Aspects of fitness and physical activity patterns in Edinburgh school children

Thesis

Link(s) to article on publisher's website:
http://dx.doi.org/doi:10.21954/ou.ro.0000e139

UNRESTRICTED

ASPECTS OF FITNESS AND PHYSICAL ACTIVITY PATTERNS IN EDINBURGH SCHOOL CHILDREN.

Kim

Susan ~~K.~~ Blackwood

A thesis submitted in partial fulfilment of the requirements of the Open University for the degree of Doctor of Philosophy

QUEEN MARGARET COLLEGE

May 1997

Author no: P9267928
Date of award: 1st August 1997

APPENDICES AND FIG 5.1 ON PAGE 145 EXCLUDED FROM DIGITISED THESIS

PLEASE REFER TO THE ORIGINAL TEXT TO SEE THIS MATERIAL

ABSTRACT

ASPECTS OF FITNESS AND PHYSICAL ACTIVITY IN EDINBURGH SCHOOL CHILDREN

There is growing concern that many children in Britain do not take sufficient exercise to benefit cardiovascular health. This is supported by extensive evidence advocating the importance of regular physical activity for lifelong health and well-being, and is of particular relevance in Scotland given it's notorious record of adult coronary heart disease death. This study examined aspects of fitness and physical activity in groups of Edinburgh school children, aged between 13 and 14 years. A three stage investigation was adopted:

Phase One: A repeated measures, same subject design was used to examine the reliability and validity of selected measures (20m shuttle run test, peak oxygen uptake (VO_2 Peak), and anthropometric measures). Thirty three children (15 boys, 18 girls) performed each test on 3 separate days. Anthropometric measures showed strong reliability ($r>0.94$, $n=33$) whilst reliability for the treadmill test of VO_2 peak and shuttle run performance was lower ($r=0.89$ and $r=0.79$ respectively). Multiple regression analysis yielded a new equation for predicting VO_2 peak for children. This age specific prediction equation incorporated shuttle run performance in conjunction with skinfold thickness measures (Boys, $R^2=0.64$ SEE=3.46; Girls, $R^2=0.79$, SEE=2.81). Repeat testing was also recommended.

Phase Two: An evaluation of methods of heart rate data analysis to assess physical activity in children. Twenty eight children (14 boys, 14 girls) wore continuous heart rate monitors (Polar Electro PE4000, Finland) over a period of 7 days (Monday to Sunday), mean duration 737 (+/-55) mins/day. A detailed 7 day self report activity diary was also completed. Variability of heart rate measures was high ($R=0.10$-0.30), and it was noted that using data for just 4 days or less resulted in considerable underestimation of total weekly activity levels (44-100% error). If activity levels are to be compared against current recommendations, researchers must endeavour to achieve weekly rather than daily estimates of activity. Evaluation of methods of heart rate data analysis showed good correlation between heart rate activity indices and reported seven day activity. For boys strongest correlation was achieved using the number of 5 minute periods with HR>139 $b.min^{-1}$ and the number of 5 minute periods with HR>50% heart rate reserve ($r=0.80$, $n=14$). Total activity time was similar for both males and females but girls engaged in fewer sustained bouts of activity (>5minutes) and a better correlate with activity in females was achieved using the total number of elevated heart rates (total HR>50% heart rate reserve, $r=0.64$, $n=14$).

Phase Three: A cross sectional survey was conducted to investigate standards of aerobic fitness and patterns of physical activity in groups of Edinburgh school children. Height, weight, skinfold thickness, shuttle run performance and physical activity (assessed by heart rate monitoring and activity diary) were recorded in a sample of 91 children (44 Boys, 47 Girls). Overall, males performed significantly better on the shuttle run test ($t=5.4$, $df=88$, $p<0.05$), had higher predicted peak oxygen uptake ($t=5.6$, $df=87$, $p<0.05$), and engaged in more bouts of moderate to vigorous activity than females. Seventy percent of boys and 50% of girls fulfilled current physical activity guidelines. Most activities were school based (131 mins per week as compared to 85 mins per week of out of school activities). Activity tended to be sporadic with active days interspersed with inactive days (mean 3.2 +/-1.6 days per week). After school activities specifically targeting young girls should be promoted.

TABLE OF CONTENTS.

	Page
Abstract	ii
Table of Contents	iii
List of Tables	viii
List of Figures	x
List of Abbreviations	xii
Acknowledgements	xiii
Declaration	xiv

	Page
CHAPTER 1: INTRODUCTION	1
Introduction	2
Research Aims	13
Research Hypotheses	14
CHAPTER 2: A REVIEW OF THE LITERATURE	15
2.1 PHYSICAL FITNESS, PHYSICAL ACTIVITY AND HEALTH	16
2.1.1 Definition of terms	
(a) Physical activity	16
(b) Exercise	18
(c) Physical Fitness	18
(d) Health	22
2.1.2 Physical Activity, Health Related Fitness and Health: The inter-relationships	23
(a) Physical activity and fitness	25
(b) Physical activity, fitness and health	26
2.1.3 Activity Recommendations	30
2.2 ASPECTS OF HEALTH RELATED FITNESS IN CHILDREN AND ADOLESCENTS	35
2.2.1 Laboratory based studies of VO_2 Peak in children	35
(a) General	35
(b) UK Studies	39
2.2.2 Field based studies of health related fitness in children	42
2.3 PHYSICAL ACTIVITY PATTERNS OF CHILDREN AND ADOLESCENTS	47
2.3.1 General Overview	47
2.3.2 Mode of Activity	54
2.3.3 Physical activity in Physical Education	56

Page

CHAPTER 3: REVIEW OF METHODOLOGIES 59

3.1 THE ASSESSMENT OF PEAK OXYGEN UPTAKE 60

3.1.1 Direct measurement of Peak Oxygen Uptake 60

3.1.2 Submaximal and field tests of aerobic fitness 63
Cycle Ergometer Tests 64
Step Tests 66
Time Distance Runs 66
The 20 Metre Shuttle Run Test 67

3.2 THE ASSESSMENT OF PHYSICAL ACTIVITY 69
Direct and indirect calorimetry 70
Doubly labelled water 71
Movement Counters 72
Self Report Measures 73
Observation and activity diaries 76
Heart Rate Monitoring 78

CHAPTER 4: PHASE ONE: THE RELIABILITY & VALIDITY OF THE 20 METRE SHUTTLE RUN TEST AS A PREDICTOR OF PEAK OXYGEN UPTAKE IN EDINBURGH SCHOOL CHILDREN AGED 13 TO 14 YEARS 86

4.1 INTRODUCTION 87

4.2 METHOD 89

4.2.1 Part (i): Reliability study and validation of the 20m shuttle run test 89
(a) Subjects 89
(b) General Procedures 89
(c) Anthropometric Measures 92
(d) Treadmill test of Peak Oxygen Uptake 95
(e) The 20m Shuttle Run Test 99
(f) Data analysis 100

4.2.2 Part (ii): Cross Validation study 101
(a) Subjects 101
(b) General procedures 101
(c) Data Analysis 102

4.3 RESULTS 103

4.3.1 Part (i): Reliability and validity of the 20m shuttle run test 103
(a) Descriptive statistics and comparison across gender groups 103
(b) Reliability analysis 105
(c) Correlation and regression analysis 108

Page

4.3.2 Part (ii): Cross validation of the new equations 116

4.4 DISCUSSION 120

4.4.1 Sample Recruitment 120

4.4.2 Reliability Study 121

4.4.3 The 20m shuttle run test as a predictor of VO_2 peak in children 128

CHAPTER 5: PHASE TWO: EVALUATION OF METHODS OF HEART RATE DATA ANALYSIS AS A MEASURE OF PHYSICAL ACTIVITY IN CHILDREN

5.1 INTRODUCTION 135

5.2 METHOD 143
(a) General procedures 143
(b) Continuous heart rate monitoring 143
(c) Seven day activity diary 146
(d) Data analysis 147
(e) Heart rate data processing 148

5.3 RESULTS 161

5.4 DISCUSSION 170

CHAPTER 6: ASPECTS OF FITNESS AND PHYSICAL ACTIVITY IN EDINBURGH SCHOOL CHILDREN, AGED 13 TO 14 YEARS. 175

6.1 INTRODUCTION 176

6.2 METHOD 180
(a) Subjects 180
(b) General procedures 181
(c) Anthropometric measures 182
(d) Shuttle run test 183
(e) Heart rate monitoring and activity diaries 183
(f) Data analysis 184

6.3 RESULTS 186

6.3.1 Shuttle run performance and predicted VO_2 peak 186

Page

6.3.2 **Activity levels** 187
(a) Seven day activity diary 187
(b) Screening of heart rate data 188
(c) Heart rate data analysis 192
(d) Quality of physical activity 199
(e) Correlation between fitness and physical activity measures 204

6.4 DISCUSSION 206

(a) Aspects of physical fitness 206
(b) Physical activity (measurement techniques) 207
(c) Physical activity levels 209

CHAPTER 7: GENERAL DISCUSSION & CONCLUSIONS 218

7.1 PHASE ONE: The reliability and validity of the 20m shuttle run test as a predictor of peak oxygen uptake in children, aged 13 to 14 years. 219

7.1.2 Research summary 219

7.1.3 Implications of the research findings 223

7.1.4 Recommendations for future research 226

7.2 PHASE TWO: Evaluation of methods of heart rate data analysis as a measure of physical activity in children. 227

7.2.1 Research summary 227

7.2.2 Implications of the research findings 232

7.2.3 Recommendations for future research 235

7.3 PHASE 3: Aspects of fitness and physical activity in Edinburgh school children aged 13 to 14 years. 236

7.3.1 Research summary 236

7.3.2 Implications of the research findings 239

7.3.3 Recommendations for future research 242

REFERENCES 245

Page

APPENDIX I:Documentation 272

(i) Letters granting ethical approval
- Lothian Health Board, 12/91 273
- Lothian Region Education Dept, 2/92 274
- Lothian Region Education Dept, 9/92 275
(ii) Letter to headteachers 276
(iii) Letter to parents
- Phase 1 277
- Phase 2 & 3 278
(iv) Consent form
- Phase 1 279
- Phase 2 280
(v) Health screening form 281
(vi) Appointment reminder 282
(vii) Schools information booklet 283

APPENDIX II: Preliminary Studies 293

Pilot (i) Calibration of the weighing scales 294
Pilot (ii) Skinfold thickness measures: Validation 295
Pilot (iii) Examination of different treadmill VO_2 peak protocols 296
Pilot (iv) Investigation of continuous heart rate monitoring techniques 298
Pilot (v) Investigation of the tickover heart rate, a measure of baseline heart rate derived from continuous heart rate data. 303

APPENDIX III: Measurement tools and materials 307

(i) Shuttle run record sheet 308
(ii) Heart rate monitoring instruction sheet 309
(iii) Activity record sheet 310
(iv) Completed activity record sheet - sample 311
(v) Pages from seven day activity diary 312
(vi) Completed page from seven day activity diary - sample 1 315
Completed page from seven day activity diary - sample 2 316

APPENDIX IV: Research publications and presentations 317

LIST OF TABLES

page

2.1 Components and factors of health related fitness, taken from Bouchard et al, 1994 — 21

2.2 Physical activity recommendations for children — 32

2.3 Reported levels of VO_2 Peak in adolescent children, 10-17 years - Non UK children — 38

2.4 Reported levels of VO_2 peak in adolescent children, 10-17 years - UK studies — 41

2.5 Reported levels of moderate to vigorous activity for children, 11-16 yrs — 52

4.1 Test order and equipment: Phase One — 91

4.2 Subject characteristics. — 103

4.3 Peak oxygen uptake and shuttle run performance by gender — 104

4.4 Intraclass correlation coefficient of reliability for each of the variables recorded over 3 separate test days (N=33). — 106

4.5 Shuttle run performance (mean +/-sd) by gender and test number — 107

4.6 Correlation matrix (Males) — 108

4.7 Correlations matrix (Females) — 109

4.8 Single variable prediction models for estimating VO_2 peak: Boys — 110

4.9 Single variable prediction models for estimating VO_2 peak: Girls — 111

4.10 Summary of multivariate regression analyses for VO_2 peak prediction from shuttle run performance & selected variables: Boys — 114

4.11 Summary of multivariate regression analyses for VO_2 peak prediction from shuttle run performance & selected variables: Girls — 115

4.12 Subject characteristics (Validation sample) — 116

4.13 Peak oxygen uptake and shuttle run performance by gender — 117

5.1 Summary statistics by gender (mean +/- sd) — 161

5.2 Summary statistics for the activity measures (mean +/-sd) — 162

5.3 Descriptive statistics for HR activity indices, mean per week (+/-sd) — 163

page

5.4 Correlation between heart rate activity indices & SDA 164

5.5 Spearmans rank correlation between selected activity indices & SDA 166

5.6 Mean activity scores by day 166

5.7 Intraclass correlation coefficient for selected heart rate measures 167

5.8 Range of activity scores according to no. of days included in analyses 168

6.1 Test order and equipment: Phase Three 182

6.2 Descriptive statistics (mean +/-sd) by gender 186

6.3 Self reported activity time in minutes per week (+/-sd) 187

6.4 No. of days recording attained 192

6.5 Summary heart rate statistics (mean +/-sd) 193

6.6 Percent of subjects and the number of sustained periods with heart rate above 119 $b.min^{-1}$ (over one week of monitoring) 194

6.7 Percent of subjects and the number of sustained periods with heart rate above 139 $b.min^{-1}$ (over one week of monitoring) 195

6.8 Percent of subjects and the number of sustained periods with heart rate above 159 $b.min^{-1}$ (over one week of monitoring) 195

6.9 Percent of subjects and the number of sustained periods with heart rate above 50% heart rate reserve (over one week of monitoring) 198

6.10 Mean heart rate (+/-sd) and duration during common sports activities 200

6.11 Pearsons product moment correlation between selected fitness and physical activity indices: Males. 205

6.12 Pearsons product moment correlation between selected fitness and physical activity indices: Females. 205

6.13 Heart rate monitoring studies for children 11 to 16 years: reported time spent in moderate to vigorous activity (mins/day) 211

7.1 The relative intensity of popular heart rate activity indices 234

LIST OF FIGURES

page

2.1 A model of fitness, physical activity and health (Bouchard et al, 1994). 23

4.1 A child undergoing the treadmill test for VO_2 Peak. 98

4.2 Relationship between VO2 peak and maximum shuttle run speed showing regression lines for males and females. 112

4.3 Prediction error: Leger et al, 1988 119

4.4 Prediction error: Barnett et al, 1993 119

4.5 Prediction error: McVeigh et al 119

5.1 Children wearing the Polar Electro heart rate monitors 145

5.2 Example of a subject's weeklong data spreadsheet file 150

5.3 Sample heart rate data trace (before screening for erroneous data) 151

5.4 Sample heart rate data trace (after screening) 151

5.5 Example of a subject's weeklong data spreadsheet file - after processing to determine the time at which each entry occured. 153

5.6 Determining the number of sustained active periods (HR >119, 139 & 159 $b.min^{-1}$) 155

5.7 Determining the minimum 15 minute moving average to establish "Tickover" heart rate. 157

5.8 Determining the number of the sustained periods with HR>20, 30, and 50 beats above tickover. 159

5.9 Calculating sustained periods with HR>50 & 75% heart rate reserve 160

6.1 Sample heart rate data trace (missing data during inactive period) 190

6.2 Sample heart rate data trace (missing data accounted for using a standard $100b.min^{-1}$ to cover the unrecorded period. 190

6.3 Sample heart rate data trace (missing data from active period) 191

6.4 Sample heart rate data trace (missing data accounted for using averaged data from other subjects. 191

6.5 Percentage of children and number of 20 minute periods attained over 1 week of testing (HR>139 $b.min^{-1}$) 197

page

6.6 Percentage of children and number of 20 minute periods attained over 1 week of testing (HR>159b.min^{-1}) 197

6.7 Typical pattern of heart rate activity during a game of FOOTBALL 201

6.8 Typical pattern of heart rate activity during a game of RUGBY 201

6.9 Typical pattern of heart rate activity during a game of HOCKEY 201

6.10 Typical patterns of heart rate activity: CRICKET PLAYERS 202

6.11 Typical patterns of heart rate activity during a game of TABLE TENNIS 202

6.12 Typical pattern of heart rate activity during GYMNASTICS 202

6.13Typical patterns of heart rate activity: DANCING/EXERCISES 203

6.14 Typical patterns of heart rate activity: PAPER ROUND 203

ABBREVIATIONS

AAHPER	American Alliance for Health, Physical Education and Recreation
AAHPERD	American Alliance for Health,Physical Education, Recreation & Dance
ACSM	American College of Sports Medicine
ADNFS	Allied Dunbar National Fitness Survey
AGS	Amsterdam Growth Study
AHA	American Heart Association
BASES	British Association of Sport and Exercise Science (formerly BASS)
BASS	British Association of Sport Science
bpm	Beats per minute
CDC	Centers for Disease Control
CHD	Coronary Heart Disease
FVFS	Forth Valley Fitness Survey (Central Regional Council, 1993)
GP	General Practitioner
Hb	Haemoglobin
HBSC	Health Behaviours Scottish Children (Currie & Todd, 1990)
HEA	Health Education Authority
HDL-C	High density lipoprotein cholesterol
Hgt	Height
LDL-C	Low density lipoprotein cholesterol
max.	Maximum
min.	Minimum
NCYFS	National Child and Youth Fitness Survey
NIFS	Northern Ireland Fitness Survey (1989)
PCPFS	President's Council for Physical Fitness and Sport
PE	Physical Education
PEA	Physical Education Authority
PWC170	Physical Work Capacity, 170 bpm
RHR	Resting heart rate
sd	Standard deviation
SDA	Seven day activity (assessed by activity diary)
SHA	Secondary Heads Association
SUM2	Sum of triceps and subscapular skinfolds
SUM4	Sum of biceps, triceps, subscapular & suprailiac skinfolds
TC	Total Cholesterol
TOHR	Tickover heart rate
UK	United Kingdom
VO_2 max	Maximal oxygen uptake
VO_2 peak	Peak oxygen uptake
YRBS	Youth Risk Behaviour Study (Centers for Disease Control, 1992)
Wgt	Weight
WHO	World Health Organisation

ACKNOWLEDGEMENTS

I would like to extend my sincere thanks to the following people:

In particular, **Dr Andrew Payne**, Senior Lecturer, Department of Physiotherapy, Queen Margaret College, for his advice and support as academic supervisor. The personal commitment and considerable time he contributed to the project are greatly appreciated.

Dr Martin Farrally, Director of PE, University of St. Andrews, Fife, for his sound academic advice and expert guidance. I owe much to his honest and constructive support and ongoing encouragement.

Ms Shona Scott, Lecturer, Department of Physiotherapy, Queen Margaret College, for acting as second supervisor and giving enthusiastic support and encouragement to the project.

My husband, **Ian Blackwood**, for his patience and tolerance over the past few years, for "counselling" during times of stress, and for ensuring that, despite work, there was always time for fresh air, sports and exercise.

Mr Richard Wilson, Senior Technician, Department of Physiotherapy, Queen Margaret College, for his much valued support and assistance during the laboratory testing sessions and for his essential role as equipment "trouble shooter".

Mr Bruce Thomson, Lecturer, Department of Communication and Information Studies, Queen Margaret College, Edinburgh. The Ben Ledi tutorial tranformed my approach to heart rate data processing

The headteachers and PE teaching staff from each of the participating schools, for welcoming me to the department, and for their generous time and assistance during the data collection.

Many thanks also to **the children** who took part. Their cooperation and enthusiastic support made the data collection period a thoroughly enjoyable and fulfilling experience. Long may they be active!

DECLARATION

Except where assistance and advice has been duly acknowledged, the research described in this thesis has been undertaken by myself and the entire thesis composed by myself

Susan Blackwood, BSc(Soc Sci), DipPS(Sports Coaching)
May 1997

CHAPTER ONE

INTRODUCTION

INTRODUCTION

It is well established that regular moderate to vigorous physical activity is beneficial to health. Since the pioneering work of Morris and co-workers (1953) which demonstrated an inverse relationship between exercise and coronary heart disease in groups of London transport workers and postal workers, there has been extensive research to identify and quantify the health benefits of fitness and physical activity. Regular exercise is inversely related to coronary heart disease incidence (Shaper and Wannamethee, 1991; Berlin & Colditz, 1990; Morris et al, 1990; Powell et al, 1987; Paffenbarger et al, 1986; Morris et al, 1953), and can protect against other chronic diseases including cancer, peripheral vascular disease and stroke (Sternfeld,1992; Wannamethee and Shaper, 1992; Linsted et al, 1991; Paffenbarger et al, 1990; Blair, 1989). In addition to fending off pathological symptoms of disease and delaying all cause mortality, regular physical activity can be of social, and psychological benefit. It is associated with an increased sense of well-being, decreased depression and anxiety (Landers & Petruzzello, 1994; Petruzzello et al, 1991, North et al, 1990), and increased self esteem (Fentem, 1992; Biddle & Mutrie, 1991; Sonstroem & Morgan, 1989; Doan & Scherman, 1987; Mutrie, 1987).

The recommended quantity and quality of physical activity necessary for optimal health still needs to be unequivocally established. Blair (1989) demonstrated a powerful inverse relationship between physical fitness and all cause mortality, thereby fueling the debate over whether it is physical fitness or physical activity that is more important for health (Rohm Young & Steinhardt, 1993; Blair, 1993; Lochen & Rasmussen, 1992; Laporte et al, 1985). Some researchers have indicated that it is moderate to vigorous exercise that reaps maximal health benefit (Rohm Young & Steinhardt, 1993; Morris et al, 1990; Morris et al, 1980). Others advocate that it is the overall level of physical activity that is important, and research has shown that exercise programs of lower intensities such as walking can have significant health benefits (Blair & Connelly, 1994; Davidson & Grant, 1993; Shaper & Wannamethee, 1991; Duncan et al, 1991). Whichever view is adopted, there is uninamity in opinion that a sensible programme of regular exercise can help to protect against chronic disease and premature death and promote quality of life, especially in the later years.

Along side the substantial body of evidence advocating physical activity for fitness and health has been growing concern that the level of physical activity amongst the general public has been in decline. People's habitual patterns of activity are continually being modified with changes in the dynamics of modern society. Scientific and technological developments over the past 50 years have had a major impact on the modern lifestyle; the workplace and home is dominated by labour saving devices, most jobs do not require vigorous exertion, there is increased reliance upon mechanised transport for day to day travel, more families own cars than ever before and whilst leisure time has increased, it has been accompanied by a rapid growth in the popularity and availability of "armchair entertainments" such as TV, video, and computer games (Blair, 1994).

In response to growing speculation and concern, a number of national surveys have been conducted in attempt to determine standards of physical fitness and patterns of habitual physical activity amongst the general populace. Most of the earlier studies were conducted in America (Presidents Council on Health and Physical Fitness, 1974; The Perrier Study, 1979; National Youth Fitness Study I and II, (Ross & Gilbert, 1985; Ross et al, 1985; Ross & Pate, 1987)), Canada (Fitness Canada, 1983) and Australia (Pyke, 1986). In Europe, early work was carried out in Czechoslovakia by Seliger & Bartunek (1971) and in the Netherlands (Amsterdam Growth Study, 1995; Kemper et al, 1989, 1986; Saris et al, 1986). It is notable that Britain has been relatively slow to adopt a national program of assessment and monitoring (Northern

Ireland Health and Fitness Survey, 1994; Allied Dunbar Health and Fitness Survey, 1992; Heartbeat Wales Technical Report, 1992; Northern Ireland Fitness Survey, 1989). In Scotland, one national survey, Health Behaviours of Scottish Schoolchildren (Currie & Todd, 1990), yielded useful information on regional differences in children's physical activity levels but did not examine activity patterns in detail. Other Scottish studies have been more localised and smaller scale (Central Regional Council & Forth Valley Health Board Fitness Survey, 1993; McCusker, 1988; Watkins et al, 1983; Farrally et al, 1980).

Results from the Allied Dunbar National Fitness Survey (ADNFS, 1992) indicated that the levels of physical fitness and physical activity of Engish adults were extremely low. It was estimated that nearly one third of men and two thirds of women had poor capacity for endurance exercise even at a moderate intensity. More alarmingly perhaps was the finding that 80% of both men and women believed themselves to be fit and the majority of these incorrectly believed that they did sufficient exercise to keep fit. Since comparable records of standards of fitness and physical activity patterns of previous generations are unavailable it is impossible to establish the existence or extent of a decline in physical activity. It is evident however, that an extremely high percentage of the general public do not take sufficient exercise to benefit cardiovascular health. Blair and colleagues (1992) estimated that an approximate 20-25% of the adult population in America are at elevated risk of premature death or disease because of their low level of physical activity. There is little to suggest that standards for Britain are any more favorable. The Allied Dunbar Fitness Survey identified that over 16% of British adults could be classified as sedentary, i.e. they did not engage in a single 20 minute period of moderate to vigorous activity in the four weeks prior to interview. Furthermore, 70% of men and 80% of women fell below their age appropriate activity level necessary to achieve a health benefit.

The relative risk of inactivity for coronary heart disease has been ranked along with smoking, hypertension and hypercholesteremia (Health of the Nation White Paper, 1992; Vaccaro & Mahon, 1989; Powell et al, 1987) and low physical activity has joined smoking, poor diet, and drug and substance abuse on the list of major preventable risk factors for chronic disease and premature death. Physical activity has thus gained soaring interest from health professionals and sports scientists on an international scale. In 1988 the first international conference on Exercise, Fitness and Health was hosted in Toronto, Canada; later followed in 1992 by an international conference on Physical Activity, Fitness and Health, also held in Toronto. These conferences provided forum for some of the world's most eminent exercise scientists to meet and discuss topical issues in the sport and exercise sciences and culminated with the production of a detailed consensus statement reflecting the current state of knowledge (Bouchard et al, 1994; Bouchard et al, 1990). Equally importantly, the gaps within current understanding were addressed and pointers for future research and development highlighted. One priority issue was the need for *"better data.... on people with low levels of activity, children and older adults and on forms of physical activity other than deliberate exercise (occupational activity, personal transportation, household chores)"* (Item No.23, Consensus statement, Bouchard et al, 1994)

Since the late 1980's, early 90's, there has been a gradual change of emphasis within preventative health strategy. The promotion of "fitness" per se has been superseded by the message of "active living for health". In Britain, regular exercise has formed an integral part of government and health board initiatives to promote community health (Health of the Nation Report, 1992; Health Education Board for Scotland, Strategic Plan, 1992) and in recognition of the important contribution that physical activity could make toward public health, a Physical Activity Task Force was set up in England in July 1993. Since then, significant steps have been taken toward the development of a national strategy for the promotion of physical activity in England including a major international symposium on the promotion of physical activity (HEA, 1994) and the recent publication of the Task Force public consultation paper (Department of Health, 1995). On a district level, some local authorities, GPs and leisure centres have set up special GP referral schemes whereby exercise can be obtained on prescription in place of conventional medicines (Kerfoot, 1994; Carrol & Green, 1993; Lord, 1993; Osbourne, 1992). Further reflecting the growing interest in exercise for health alongside the conventional focus on sport and physical fitness, The British Association of Sport Science (BASS) recently changed it's official label to the British Association of Sport and Exercise Science (BASES) (BASES Newsletter, November Issue, 1993).

Whilst the clinical symptoms of chronic disease may not become apparent until later life, many of the disease processes become manifest during the early childhood years (Strong et al, 1972; Strong & McGill, 1969) and some health professionals have urged that health promotion strategies must extend their predominantly adult oriented approach to also target the young (Vaccaro & Mahon, 1989). It is recognized that the early stages of atherosclerosis appear in infancy and develop throughout childhood and adolescence (Vaccaro & Mahon, 1989; Newman et al, 1986). Several studies have indicated that a considerable number of children (approximately 20%) exhibit two or more risk factors for coronary heart disease by age 15 (Boreham et al, 1993; Fripp et al, 1985; Lauer et al, 1975; Wilmore & McNamara, 1974). In addition, many behavioural characteristics associated with coronary heart disease incidence, including smoking, drinking and exercise habits, are adopted during childhood and carried into and throughout adulthood with marked consistency (Webber et al, 1983; Nora, 1980). Results from the Allied Dunbar survey (1992) indicated that those people who exercised regularly during youth were more likely to continue or resume exercise in later years. It has also been demonstrated that childhood fitness scores are indicative of physical activity levels in adulthood (Dennison et al, 1988). Such evidence suggests that any sedentary trend in the patterns of activity of today's youth could have serious implications for future health and warrants immediate counteractive intervention (Riddoch et al, 1991a).

There are many reasons to suspect that children's habitual physical activity levels may be in decline. As with the adult occupational and leisure environment, the child's school and leisure environment has been altered dramatically over recent years. For many, the city environment is incompatible with street play, opportunities for spontaneous outdoor games has decreased, children can no longer play "kick about " in the streets, roads are often too dangerous to cycle on, and many of the streets are deemed unsafe for minors to walk unaccompanied. The number of primary school children who walk to school has fallen by almost 20% between the years 1971 and 1990 (Hillman et al, 1993). The government Physical Activity Task Force has proposed that the decline in habitual activity may be due in part to the increase in home based leisure activities such as computer games and videos (Department of Health, 1995). Publicity material produced by computer games industries would certainly indicate that they have identified the young population as a lucrative market and the widespread appeal of these alternative forms of entertainment provides an unfortunate disincentive to exercise or to partake in traditional sports and games.

Physical education in schools provides an essential service to children and adolescents, enabling the development of motor skills, encouraging socialization, and promoting cardiovascular health. It is estimated that school based activity may constitute the only exercise for over one third of all children, 11 to 18 years (Scottish Sports Council Research Digest, 1993; Northern Ireland Fitness Survey, 1989). It is with concern therefore that recent surveys indicate a reduction in PE time within the school curriculum in Scotland (Scottish Sports Council, Edinburgh, 1989). During the teachers strike action of the 1980's extra-curricular work undertaken by teachers dropped dramatically and whilst voluntary contribution by teachers has since increased the volume has not returned to pre-dispute levels (Sports Council, 1990). A report by the Secondary Heads Association (1991) indicated that the percentage of state school children of age 14 who had less than 2 hrs/week PE increased from 38% in 1987 to 71% in 1990. It was also observed that the average number of PE hours per week in British state schools was one of the lowest in Europe (Armstrong and McManus, 1994). There is a need to establish more fully, the extent to which compulsory PE contributes to children's levels of physical activity and physical fitness and to develop programmes to promote regular exercise both in the leisure and school settings.

Determining the extent of the problem of a sedentary trend in children has been hindered by the lack of clear recommendations of optimal exercise levels. Most research upon which recommendations for children have been based has been carried out in America, Canada and the Scandinavian countries. Research on the fitness and physical activity patterns of children in Britain was limited prior to the late 1980's but has derived more interest in recent years. Most notable, has been the work of Dr Neil Armstrong and his colleagues at Exeter University, England (1989 - 1994), the Northern Ireland Fitness survey (NIFS, 1989), the Heartbeat Wales Study, (1987); the Young Peoples Leisure and Lifestyles Project, Scotland (Hendry et al, 1989), the Health Behaviours Scottish Children survey, (HBSC, Currie & Todd, 1990) and more locally, a Stirling based study (McCusker,1988) and the Forth Valley Fitness Survey, FVFS (Central Regional Council & Forth Valley Health Board, 1993). The majority of studies looked at types, frequency and duration of exercise based on self report questionnaire or interview, only the English studies endeavoured to assess intensity of exercise using objective physiological measure.

Part of the problem with any study of fitness and physical activity patterns is the lack of standardised methods of assessment. Health related fitness has many components and cannot be expressed by a single global measure; aspects of muscular strength and endurance, flexibility, cardiorespiratory endurance, and body composition should all be considered. A strong inverse relationship has been demonstrated between cardiorespiratory endurance (as measured by maximal oxygen uptake) and coronary heart disease risk in adult men (Cooper et al, 1976) and women (Gibbons et al, 1983) and it is this measure that has dominated health related fitness research. Laboratory tests of maximal oxygen uptake can provide a reliable and valid measure of cardio respiratory fitness in adults but due to equipment and cost it is unsuitable for large epidemiological studies. Furthermore, its status as the "gold standard" of aerobic fitness measures has been thrown into question (Sharkey, 1991). Aerobic performance is a somewhat intangible concept given that endurance events may range from 5 minutes to many hours. It seems unlikely that a single measure can adequately address the wide range of performance outcomes encompassed within the "aerobic fitness" umbrella. Nevertheless, given its historical status and demonstrable merit as a highly standardized and reproducible measure, maximal oxygen uptake is likely to retain a prominent role in health related fitness research. It is arguably the only measure where, due to well established and rigorous international laboratory protocols, cross study comparison may be made with any degree of confidence.

Many researchers have sought to develop field tests for predicting maximal oxygen uptake (VO_2 max). Ideally such a measure would enable more rigorous study of cardio respiratory fitness in groups hitherto largely excluded from VO_2 max testing, (eg children, the elderly, the mentally ill). Whilst both sub-maximal and maximal field methods have been devised and many are popular for training purposes, education and health promotion, none of the existing measures can demonstrate reliability to a standard comparable to the laboratory based measure. Simons Morton and colleagues

(1987) stressed that large scale studies of population sub-groups are severely limited without further development of improved methods of field testing better correlated with VO_2 max levels.

One field test, the 20 metre shuttle run test (Leger et al, 1982) has been shown to be particularly useful for the assessment of groups. It's simple design, (a paced running test) uses minimal equipment, is easy to administer and enables several people to be tested at the same time. It is popular in many schools for fitness assessment within the PE curriculum. Whilst good correlation with maximal oxygen uptake in adults has been demonstrated (Leger et al, 1982) the relationship between shuttle run performance and peak oxygen uptake in children is less clearly established (Armstrong et al, 1988). Shuttle run performance of children and adolescents appears to be dependent on age/physical maturity (Leger et al, 1988). The influence of maturational differences (especially, body composition) on children's performance needs further investigation (Barnett et al, 1993; Riddoch et al, 1992).

Physical activity assessment is similarly problematic. As with physical fitness, physical activity has several dimensions (mode, intensity, frequency, duration) and as yet there is no ideal tool for describing or quantifying fully the nature of individual habitual physical activity patterns (Baranowski et al, 1992). Questionnaires, direct observation, mechanical devices (step counters, pedometers, accelerometers), and physiological measures (energy intake, oxygen uptake, heart rate monitors, doubly labelled water), are all available but none provide a multidimensional measure. Heart rate monitoring has proved to be a popular method in studies with children (Payne et al, 1995a, 1995b, 1994; Durant et al, 1993,1992; Livingstone et al, 1992; Armstrong et al, 1991, 1990; Spurr & Reina, 1990; Freedson, 1989) and if used in conjunction with activity diaries and/or questionnaires, a detailed activity profile describing, mode, frequency, intensity and duration of activity can be achieved. Unfortunately the lack of standardized interpretive methods introduces an element of subjectivity upon a potentially objective measurement tool. Different authors have adopted different definitions of what constitutes an "active period" from the heart rate data. Some researchers have selected the cut off points of 140 and 160 beats per minute to indicate moderate and vigorous activity (Sallis, 1993; Riddoch et al, 1991b; Armstrong, 1991, 1990, 1989), others have chosen to express heart rate levels relative to resting heart rate (Durant et al, 1993, 1992), heart rate reserve (Janz et al, 1992) or to heart rate during sleep (Atkins et al, 1995). Those interested in actual energy expenditure have established individual calibration curves for the heart rate/ oxygen uptake relationship and defined moderate and vigorous activity according to a percentage of peak oxygen uptake (Livingstone et al, 1992; Spurr & Reina, 1990; Verchuur & Kemper, 1985). None of the established methods can be classified as ideal and only guarded conclusions may be drawn from individual studies. Furthermore, the lack of consensus in research approach means that opportunity for comparison between studies is severely limited.

In summary, there is a dearth of information regarding fitness and physical activity of Scottish youth. Given Scotland's notoriously high record of coronary heart disease incidence (Uemera & Piza, 1988), all potential areas of weakness (including fitness standards and exercise habits) need to be scrutinized. Research of this kind is severely restricted by the lack of standardized field based methods for the assessment of children's health related physical fitness and physical activity. Whilst popular and cleverly designed measures of aerobic fitness are available (the 20m shuttle run test), their use within specific age groups of children has not be explored in detail and the impact of maturational changes (especially, body composition) needs careful evaluation. Similarly, whilst technological advancement has enabled the development of sophisticated and highly accurate physiological devices (such as heart rate monitors) for the measurement of physical activity levels, the variety of measurement protocols commonly adopted by researchers, have not been scientifically validated. In particular, the number of days necessary to gain an accurate measure of activity has not been established. There is thus a need for a thorough review of current methods for the assessment of health related fitness and physical activity, accompanied by the development of tests appropriate for use with children.

The following study was developed as a 3 phase investigation. A survey of fitness and physical activity patterns in children in Edinburgh was preceded by 2 preliminary phases examining selected field measures of aerobic fitness and physical activity measures in children. This format enabled careful evaluation and development of all tools and procedures.

- Phase 1: An investigation to examine the reliability and validity of the 20m shuttle run test as a predictor of peak oxygen uptake in children. Building on previous research, the relationship between shuttle run performance, peak oxygen uptake and body composition (skinfold thickness measures) was examined. To control more carefully for age, a restricted age range was selected (13 to 14 years).

- Phase 2: An evaluation of methods of heart rate data analysis for assessing physical activity in children. Several popular methods of heart rate data analysis were examined with particular emphasis on determining the effects of measurement protocol (number of days of assessment, and selected analytical procedures) on physical activity score.

- Phase 3: A descriptive survey investigating aspects of physical fitness and physical activity patterns in Edinburgh school children, 13 to 14 years.

RESEARCH AIMS

Phase 1: Field based assessment of aerobic fitness in children	
Part (i):	To examine the reliability of shuttle run performance, peak oxygen uptake and standard anthropometric measures in children, 13 to 14 years. To examine the validity of the 20 metre shuttle run test as a predictor of peak oxygen uptake in children, aged 13 to 14 years, and To develop prediction equations for estimating VO_2 peak from shuttle run performance appropriate for use with 13 to14 year old children.
Part (ii):	To evaluate the effectiveness of these equations by cross validation with a second sample of children, also aged 13 to 14 years.
Phase 2: Physical activity assessment in children	
Part (iii):	To conduct an exploratory investigation of heart rate monitoring measurement and analysis techniques In particular, to assess the variability of heart rate across 7 days and thus determine the number of days of measurement necessary to gain accurate measure of week long activity. To assess the validity of selected heart rate measures against 7 day activity diary records.
Phase 3: A descriptive survey of aspects of fitness and physical activity in children	
Part (iv):	To examine sex differences in the levels of shuttle run performance and predicted peak oxygen uptake in Edinburgh school children, aged 13 to 14 years.
Part (v):	To examine sex differences in the levels and patterns of physical activity. To evaluate the extent to which these children achieve current recommended levels of physical activity To examine the relationship between physical fitness measures (shuttle run performance, predicted peak oxygen uptake and anthropometric measures) and physical activity (derived from continuous heart rate data) in children, 13 to 14 years.

RESEARCH HYPOTHESES

The Null Hypotheses

A_0 The prediction of VO_2 Peak from shuttle run performance is not improved by the addition of anthropometric measures in the prediction equation

B_0 The prediction of VO_2 Peak from shuttle run performance is not improved by the use of repeat testing to gain better estimate of maximal performance

C_0 Increasing the number of days of heart rate measurement does not provide a better estimate of physical activity levels.

D_0 There is no sex difference in the levels of shuttle run performance and predicted peak oxygen uptake in Edinburgh school children.

E_0 There is no sex difference in the levels and patterning of physical activity in Edinburgh school children.

Alternative Hypotheses

A_1 The prediction of VO_2 Peak from shuttle run performance is improved by the addition of anthropometric measures in the prediction equation

B_1 The prediction of VO_2 Peak from shuttle run performance is improved by the use of repeat testing to gain better estimate of maximal performance

C_1 Increasing the number of days of heart rate measurement provides a better estimate of physical activity levels.

D_1 There is a significant sex difference in the levels of shuttle run performance and predicted peak oxygen uptake in Edinburgh school children.

E_1 There is a significant sex difference in the levels and patterning of physical activity in Edinburgh school children.

CHAPTER TWO

REVIEW OF THE LITERATURE

2.1 PHYSICAL ACTIVITY, FITNESS AND HEALTH.

Prior to any analytical investigation it is essential that the main terms of reference are clearly defined. The terms, physical activity, physical fitness, exercise and health all enjoy regular usage by the general public and are treated with a familiarity and ease that is rarely extended to more scientific jargon. Unfortunately such regular and popular usage has tended to encourage a certain casualness in application and the terms are often used incorrectly and sometimes interchangeably with one another (Casparsen et al, 1985). The most recent and widely accepted definitions are those devised during the 1992 International Consensus Symposium on Physical Activity, Health Related Fitness and Health, Toronto, Canada (Bouchard et al, 1994). The consensus statement which accompanied this conference details the current state of knowledge within the sport and exercise sciences and provides the most up to date, comprehensive and internationally accepted standpoint on physical activity, health related fitness and health issues. These definitions are provided below along with a brief review of significant earlier definitions now largely superseded.

2.1.1 Definition of Terms

(a) Physical Activity

One of the most popular definitions of physical activity was developed by Caspersen and colleagues (1985);

> *"Physical activity is defined as any bodily movement produced by the skeletal muscles that results in energy expenditure."* (Caspersen et al, 1985, p126).

According to this definition, physical activity is universal to all living persons. It is part of daily living and everyone, from the Olympic athlete to the bed ridden invalid, will be physically active to a greater or lesser degree. The main measurable components of physical activity are mode, frequency, duration and intensity. Mode of physical activity is diverse being dependent upon the muscle group engaged, the nature of the contraction (concentric, eccentric, isometric), and the sequential patterning of those muscle movements. Duration and frequency may be measured in unit time and time per period respectively, whilst intensity may be measured according to the level of energy expenditure. Physical activity may thus be classified in many ways; according to the muscle group engaged, according to the nature of the movement and the context in which it is performed, or according to specific portions of daily activity. Various techniques for the assessment of physical activity are detailed in Chapter 3, "Review of Methodologies".

Under the 1992 consensus statement on physical activity, health related fitness and health, Caspersen and colleagues' definition was subtlely modified by the inclusion of the word "substantial". The new definition states that;

> *"physical activity comprises any body movement produced by the skeletal muscles that results in a* ***substantial*** *increase over the resting energy expenditure"* (Bouchard et al, 1994, p.11; consensus statement).

This serves to clarify the obvious paradox that the extremely sedentary could, under the former definition, be said to be active (if only to a limited degree), and removes possible confusion over the classification of small muscle movements. It does however bring with it associated complications of how to quantify the precise meaning of "substantial" and the introduction of a theoretical "cut off" point below which a skeletal muscle movement does not constitute physical activity presents a philosophical conundrum.

(b) Exercise

Exercise comes under a special sub category of physical activity and is defined as;

> *"... a subset of physical activity that is planned, structured and repetitive and has as a final or intermediate objective the improvement or maintenance of physical fitness."* (Caspersen et al, 1985, p126).

Under this widely accepted definition, all physical exercise is physical activity and physical activity is physical exercise if it is carried out for the purpose of promoting or maintaining fitness. Thus a day to day activity such as "walking the dog" could be classified as either "physical activity" or "exercise" depending on the intention of the walker on the outset.

(c) Physical Fitness

Physical activity and physical exercise are related to movements people perform. In contrast to this, fitness is a state of being that is both transitory and multidimensional. Many attempts at definition have consequently been plagued by inherent ambiguity. Popular definitions, employed for more than 20 years, have been The World Health Organisation definition of fitness as;

> *"the ability to perform muscular work satisfactorily"* (WHO,1968)

and that proposed by the President's Council on Physical Fitness and Sports (1971), which defined fitness as;

> *"the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure time pursuits and meet any unforeseen emergencies".*

More recently, the WHO definition was criticised for the use of the term "work" since this implied movement of a mass through a distance and ignored the potential for isometric muscle activity (Gutin et al, 1992). The proposed amendment was;

"the ability to carry out physical activity satisfactorily" (Gutin et al, 1992).

All such definitions have been deliberately loose and non-specific in order to encapsulate the various qualities that pertain towards a concept of "fitness". Such words as "satisfactorily" and "ample" have been carefully chosen and serve to acknowledge that the concept of "fitness" is highly subjective. Unfortunately, however, these definitions provide no concrete framework upon which to structure objective assessment of "fitness" levels.

The problem beset by broad definition was counteracted by the definition proposed by Caspersen et al (1985): *" Physical fitness is a set of attributes that are either health related or skill related. The degree to which people have these attributes can be measured by specific tests".* The main measurable components of physical fitness were identified and grouped into two broad categories; health related physical fitness and skill related physical fitness (Caspersen et al, 1985, p128).

Health Related	***Skill related***
Cardio- respiratory Endurance	Agility
Muscular Endurance	Balance
Muscular Strength	Co-ordination
Flexibility	Power
Body Composition	Reaction Time
	Speed

Within each of these components, fitness varies from low to high and can be assessed by specific tests. The components may not necessarily vary in unison for a given individual. A person may have high muscular and cardio-respiratory endurance but low flexibility; and even within one fitness component, levels may vary between body sites: for example, muscular strength may vary markedly between the muscle groups. It has been shown that this multi-dimensional structure of physical fitness generalises over age and gender (Marsh 1993).

Whilst making the concept of "physical fitness" conceptually manageable and essentially measurable, this definition is not without arguable flaw. It has set the way for classifying the most important components for fitness but by no means provides the definitive version and may in fact blinker the wider view of health related physical fitness that former definitions preserved. Evidence of other health related aspects of physical activity are emerging from the research literature. Relationships between physical activity and blood pressure, blood lipids, insulin sensitivity, glucose tolerance, and bone density have been established (Haskell, 1994; Haskell, 1984; Manson et al, 1991; Helmrich et al, 1991; Wickham et al, 1989; Dalsky et al, 1988; McCunney, 1987). It is arguable that each of these measures are also legitimate components of health related fitness and should be added to the list. Bouchard and colleagues (1990), proposed the following:

Fitness in a general sense, *"can be conceived of as the matching of the individual to his or her physical and social environment"* (Bouchard et al, 1990, p6)

In accordance with this view, at the International Consensus Symposium on Physical Activity and Health, exercise scientists agreed that "fitness" in it's broadest sense should include both physical fitness (as per the WHO definition, 1968) and physiological fitness, which extends to biological systems influenced by the level of habitual physical activity (Bouchard et al, 1994, 1990). Bouchard et al (1994) expanded Caspersen's list of components of health related physical fitness to include other indicators of the body's physiological and biological state (Table 2.1 below).

Table 2.1: Components and Factors of Health Related Fitness, taken from Bouchard et al (1994)

Morphological Component	*Motor Component*	*Muscular Component*
Body Mass for height	**Agility**	**Flexibility**
Body Composition	**Balance**	**Power**
Subcutaneous Fat Distribution	**Co-ordination**	**Strength**
Abdominal visceral fat	**Speed of Movement**	**Endurance**
Bone Density		

Cardiorespiratory Component	*Metabolic Component*
Submaximal exercise capacity	**Glucose tolerance**
Maximal Aerobic Power	**Insulin Sensitivity**
Heart Functions	**Lipid and Lipoprotein metabolism**
Lung Functions	**Substrate oxidation characteristics**
Blood Pressure	

This definition by Bouchard and colleagues (1994), with specified components and factors selected on the basis of scientific evidence, provides the most comprehensive definition of fitness as yet available. The expansion of the definition however, may not stop there and the list of components of health related fitness is not yet exhausted. Given appropriate scales of measurement, "fitness" profiles could potentially include psychological and social factors (in addition to physiological components) since they too can be influenced by physical activity levels (Gutin et al, 1992). "Physical fitness" per se is thus an ever expanding concept. With the continued identification of important components of health related fitness, and improved means of assessment, the development of an holistic "fitness" profile becomes ever more attainable, even if somewhat unwieldy.

(d) Health

As with the physical activity and health related fitness, health is a multifaceted construct. Accompanying its numerous dimensions are numerous scales of measurement including; mortality, morbidity, risk factor prevalence, use of medical care, disability, function (physical mental and functional activities), well-being (bodily, emotional, self concept, global perceptions of well-being), healthy life years (Caspersen et al, 1994). One of the most widely quoted and long standing definitions of health is that used by the World Health Organisation;

> *Health is "a state of complete physical, mental and social well- being and not merely the absence of disease or infirmity"* (Constitution of the WHO, 1948)

This definition of health was also elaborated upon following the 1988 and 1992 fitness, physical activity and health consensus symposiums and the following was proposed:

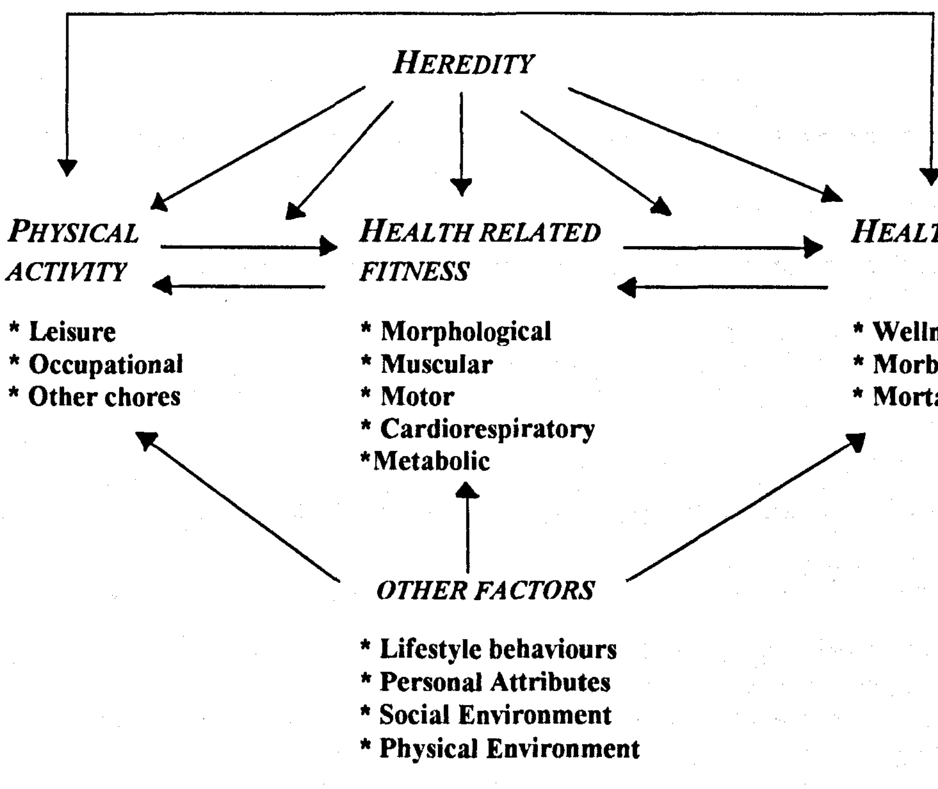
> Health is *"a human condition with physical, social and psychological dimensions each characterised on a continuum with positive and negative poles. Positive health pertains to the capacity to enjoy life to withstand challenges; it is not merely the absence of disease. Negative health pertains to morbidity and in the extreme, premature mortality."* (Bouchard et al, 1990)

Bouchard and colleagues (1994, 1990) stress that positive and negative status may coexist with opposing status of other dimensions i.e. physical, social and psychological health status do not run in parallel and can vary asynchronously.

2.1.2 Physical Activity, Health Related Fitness and Health: The Inter-Relationships

Physical activity, health related fitness and health constitute a triad of complex inter-relationships, summarised in a model developed by Bouchard and colleagues (1994) and illustrated in Figure. 2.1 below.

Fig 2.1: A Model of Fitness, Physical Activity and Health (Bouchard et al, 1994)



As is demonstrated, over-riding all three factors is an heredity component which plays a very large role not only in determining individual status but also the nature of the relationship between each of the elements. The contribution of genetic factors to individual differences in the level of habitual physical activity has been estimated at approximately 30% (Haskell, 1994; Perusse et al, 1989). There is also a significant genetic effect on most components of physical fitness estimated at 25 - 50% for body composition, over 50 % for muscular and motor fitness, and 20 - 30% for maximal aerobic power (Haskell, 1994, Bouchard et al, 1992). Genetic factors may also influence the response to environmental stimuli so no two individuals will show the same physiological response to a bout of physical activity (Bouchard et al, 1992). Underlying each of the three elements are other factors, social, psychological and environmental, which can have significant influence upon physical activity patterns, physical fitness and health at any point in time.

Most of the relationships are reciprocal. Physical activity levels may influence health status but current health status will also influence the levels of physical activity undertaken. Likewise, whilst physical activity level can impose direct influence upon fitness status, the level of cardiorespiratory fitness may also directly affect the level of participation in physical activity. It has been shown that individuals with higher cardiorespiratory fitness are more likely to engage in strenuous occupational and leisure time activities than those of poor physical fitness (Dishman et al, 1985).

Whilst the model provides a good framework upon which to examine the inter-relationship between fitness, physical activity and health, it should be noted that it is based predominantly on evidence yielded by studies on adult populations. Whether many of the relationships indicated are equally applicable to child populations is unclear. The nature of the relationships between physical activity, physical fitness and health in children is obscure and even the most rigorous research methodology is unable to control completely for the confounding effects of maturation and growth. In addition the listed indicators of health status (morbidity and mortality) may be less pertinent in child populations with physical activity and fitness being more strongly correlated to measures of body fat, bone mineral density, and psychological health than for risk factors for (or death from) chronic disease.

(a) Physical activity and aerobic fitness

In adults, there is a clear relationship between the level of physical activity and aerobic fitness (as defined by maximal oxygen uptake). The physiological response to exercise conforms to a set of general rules, (principle of overload, law of diminishing returns, principle of specificity, principle of reversibility; Astrand & Rodahl, 1986). Adults who engage in physical exercise 60 - 80% of maximal functional capacity, 3 to 4 times per week, 20 to 30 minutes duration and of a nature involving large muscle groups, show corresponding improvements in aerobic power and endurance performance (ACSM, 1990). In children however, there is debate as to whether this powerful relationship exists (Payne & Morrow, 1993; Simons Morton et al, 1987; Borms, 1986; Rowland, 1985).

Whilst several studies have indicated that children are aerobically trainable and can demonstrate improvements in peak oxygen uptake following a programme of moderate to vigorous exercise (Krahenbuhl et al, 1985; Stewart & Gutin, 1976) other authors have argued that many children appear to exhibit a high level of VO_2 Peak despite engaging in very little activity (Armstrong et al, 1989; Klissouras, 1971). The nature of the findings are often dependent on the age and maturity of the study group. The relationship between cardiorespiratory fitness and physical activity levels appears to be weakest during puberty (Bar-Or, 1989; Weymans et al, 1986; Katch, 1983; Weber et al, 1976) and several reviews of the effects of physical training on aerobic exercise in children have concluded that children show limited improvements in aerobic fitness following a programme of exercise prior to and during puberty (Payne & Morrow, 1993; Vaccaro & Mahon, 1987; Borms, 1986; Rowland, 1985).

In many of the studies investigating the relationship between aerobic fitness and activity, it is difficult to establish whether the low correlations between physical activity and physical fitness are due to the fact that there is little or no relationship between the two variables or whether it is simply that the measurement tools used fail to quantify physical activity adequately. In a large study of 2352 children, 8 to 9 years of age, Pate et al (1990) studied the relationship between physical fitness measures (assessed by 1.6 Km run/walk time and skinfold thicknesses) and children's level of activity (as measured by parent and teacher five point rating of activity). Weak, but notably significant, correlations were identified between the activity and fitness measures (r= 0.17-0.33). Whilst, the simple 5 point rating of activity as used in this study can often provide a useful summary of an individual's habitual activity level, it is a crude and subjective means of classification and is likely to be subject to considerable error. It is suspected that as methods of physical activity assessment are improved, better correlation between VO_2 peak and physical activity may emerge.

(b) Physical activity, physical fitness and health

The relationship between physical activity, physical fitness and health in childhood is similarly obscure. The extensive benefits of regular physical activity on adult health are well documented (Bouchard, 1994; Royal College of Physicians, 1991). Positive biological changes include skeletal muscle hypertrophy, increased capillarization and maximal blood flow, increased substrate availability and metabolic capacity, increased strength and endurance, increased stroke volume and cardiac output at rest and during exercise, and lower heart rate and blood pressure at rest and during submaximal exercise (Haskell, 1994; Astrand & Rodahl, 1986; Blomqvist & Saltin, 1983). The list of benefits extends further as an ever accumulating body of evidence links physical activity with the prevention and control of high blood pressure, decreased tendency for blood clotting, improved lipoprotein profile, increased insulin mediated glucose uptake, decreased adiposity, and prevention of osteoporosis (Haskell, 1994; Drinkwater, 1993; Henriksson, 1992; Helmrich et al, 1991).

The inverse relationship between regular physical activity, and coronary heart disease (CHD) risk is well established in adults (Linsted, 1991; Berlin & Colditz, 1990; Powell et al, 1987; Paffenbarger et al, 1986) but is more tenuous in child research. Macek and colleagues (1989), compared risk factor profiles of groups of trained and untrained adolescent boys, 15 to 18 years and concluded that those children who had trained in athletics for a number of years had more favourable lipid profiles and lower physical and behavioural risk factors. This supported earlier studies which reported a negative correlation between cardiorespiratory fitness and blood pressure (Tell and Vellar, 1987; Frazer et al, 1983). More recently, Payne and colleagues (1995) identified an inverse relationship between energy expenditure and blood cholesterol levels in children aged 6-8 years, and in adolescents, Suter and Hawes (1993) report that high levels of physical activity were associated with improved blood lipid profiles, particularly for males. Contrary to these findings however, some researchers have been unable to identify any significant relationship between cardiorespiratory fitness or physical activity levels and CHD risk (Armstrong et al, 1991; Kwee and Wilmore, 1990). Vaccaro and Mahon (1989) and Montoye (1986) conducted extensive independent reviews of the effects of exercise on coronary heart disease risk factor prevalence in children. Both reached the disappointing conclusion that current evidence failed to demonstrate a strong link between physical fitness, physical activity and coronary heart disease risk in children. The only risk factor that has been consistently related to exercise within the research is obesity (Rowland, 1991).

Part of the problem may be the time scale and design of most research (predominantly, cross-sectional) and the mismatch with the considerable length of time it may take risk factors to develop or change. Montoye (1986) has proposed that exercise may require a long period of time to bring about any measurable change to risk factor profiles in children. In support of this, Hansen and co-workers (1991) found that physical training could bring about beneficial changes to risk factor profiles in children but noted that the physiological adaptations were very slow to bring about significant effect (up to 8 months). It is speculated that many other health benefits of exercise may take years, if not decades, before they are apparent and without intensive longitudinal research covering a life span, (if not several generations), the long term benefits of exercise cannot be conclusively determined.

The debate over the relative merits of physical fitness and physical activity for cardiovascular health is ongoing (Pate, 1995; Blair, 1994; Blair & Connelly, 1994). Further research is necessary to clarify the precise nature of the relationship between fitness, physical activity and health (Pate, 1995) and with the matter unresolved within adult research, to establish a definitive answer for children remains even more elusive. Pate (1995, p.313) raised three important issues "*(a) how much and what types of physical activity are needed for each of the specific health benefits that have been associated with physical activity (b) is there an optimal amount of physical activity and (c) is there a minimal amount of activity that should be endorsed?*" Answers to each of these questions is dependent upon determining the nature of the dose response relationship between physical activity and health, i.e. just how much exercise relates to how much health benefit?

The dose response issue has been the subject of considerable debate over recent years and remains a key area of research. Growing evidence supports that physical activity is inversely related to chronic disease morbidity and mortality and that a graded (possibly curvilinear) relationship is apparent (Blair, 1994). It is accepted however that the relationship between physical activity and other health parameters may be very different and that both the type and intensity of physical activity undertaken have important bearing on the nature of the health benefit. For example, whilst it is aerobic type activity that is related to the prevention of coronary heart disease, it is specifically weight bearing exercise which promotes bone mineral density and protects against osteoporosis (Drinkwater, 1993; Dalsky et al, 1988). Similarily, whilst it is moderate activity which has been shown to be most beneficial in lowering blood pressure in patients with hypertension (ACSM, 1993), preliminary evidence suggests that it is vigorous activity which is associated with the prevention of non-insulin dependent diabetes mellitus (Helmrich et al, 1991) and with certain health measures, such as high density lipoprotein cholesterol levels and/or weight control, it is total energy expenditure which is important and the actual exercise intensity may be less relevant (Pate, 1995; Duncan et al, 1991).

It is clear that there is still much to be done to clarify these dose-response issues within physical activity and health. In particular, it is important to establish the differences between adults and children in terms of their patterns of exercise behaviour and physiological responses to physical activity. Whilst these issues are still under review, and the precise benefits and optimal levels of exercise are unclear, there is a general consensus that regular moderate to vigorous physical activity is extremely important for children's development. Whether or not a child gains substantial benefits from exercise in terms of cardiovascular conditioning, weight control or blood lipid control, there is much to be said for providing children with the necessary skills to enjoy regular exercise and to encourage a positive attitude toward regular participation. It is hoped that children can then carry over the "good practice" into adulthood where demonstrable benefit in terms of health status can be achieved (Livingstone, 1994; Simons Morton et al, 1987). The main rationale for advocating regular exercise in youth at present is thus, not so much driven through a need to improve their current fitness and health profiles, but simply to encourage the development of healthy habits and the acquisition of necessary skills to promote the continuation of the exercise habit in adulthood (Livingstone, 1994; Simons Morton, 1987).

In line with this reasoning, it has been necessary, despite the acknowledged gaps in current understanding, for researchers, health professionals and government agencies alike to strive to establish physical activity guidelines. For the present, the setting of optimal levels of physical activity for health has been avoided but progress has been made towards establishing recommended minimal levels of physical activity (Pate et al, 1995, Sallis & Patrick, 1994; Fletcher et al, 1990). Proposals for the recommended minimal levels of physical activity are detailed in the following section. It should be noted that whilst aerobic type activity has tended to dominate these health related exercise guidelines, more recently it has been recognised that activity to promote muscular strength, muscular endurance, flexibility, and bone mineral density must not be neglected and that a range of different activities should be supported (Pate et al, 1995, Fletcher et al, 1990).

2.1.3 Activity Recommendations.

The American Heart Association (Fletcher et al, 1990) published a special report on exercise standards for health professionals and recommended the following exercise prescriptions. One recommendation was for the maintenance of good cardiovascular health, the other for the purposes of physical training:

1) Exercise for maintenance of cardiovascular health:

"Regular physical activity is important for health maintenance. Walking appears to be as beneficial as more vigorous activities. Some benefit is apparently derived from as little as 20 minutes of low intensity exercise performed three times per week. However, incremental benefits appear to accrue from up to 2000 calories per week (20 miles of walking or jogging). There is no evidence of a health benefit at more than 2000 calories per week."

2) Exercise for physical training

"Activities that cause the greatest increase in VO_2 max have certain characteristics that, when present are said to qualify the exercise as endurance or cardiovascular. These characteristics include dynamic exercise, alternately contracting and relaxing the muscles (as opposed to isometric or static exercise), and large muscle group activities such as walking or running. Exercise must be performed at least three times per week for a minimum of 20 - 30 minutes per session, at a minimum intensity of 50 - 60 % VO_2max....."

Similar recommendations have been listed by the American College of Sports Medicine which specify large, dynamic muscle movement, 50 - 85% maximum functional capacity, 20 to 30 minutes duration and for 3 to 5 times a week (ACSM, 1990). It has been acknowledged that these aims are perhaps rather ambitious for the large sedentary sector of the population and that the greatest benefit in terms of national health could be gained by encouraging the least active sector of the community just to "do a little more". A recent Health Education Authority symposium on physical activity indicates a noticeable shift in emphasis from the traditional view of vigorous exercise 3 times a week to the promotion of moderate exercise (such as brisk walking) at least five times a week (HEA, 1995). In addition new guidelines recognise that most activity may be accumulated throughout the day rather than taken in one continuous session (Pate et al, 1995).

Walking activity has received particular commendation as is typified by the recent Health Education Authority guidelines (1995) and the Royal Society for Health document “Take a Walk” (Crombie, 1995). As a form of exercise for mass participation it has many advantages; it is appealing to a wide range of people, does not demand the development of complex motor skills, is low impact, thus minimising risk of soft tissue injury, is low cost and has been shown to have significant health benefits, in particular promoting lipoprotein profiles and maintaining joint mobility and endurance in later years (Davidson & Grant, 1993; Duncan et al, 1991; Haskell, 1985). It is perhaps surprising however that a form of activity that was advocated as far back as the time of Hippocrates, has taken so long to be acknowledged within modern day health promotion strategy.

The level of exercise necessary for fitness and health in children is less clearly established and the rationale for advocating various forms of activity extends far beyond issues of health and recreation. Nevertheless, accepting that it is inappropriate to simply transfer adult guidelines onto child and adolescent groups, and in attempt to tackle ongoing concerns regarding standards of youth fitness, several researchers have developed recommendations specific for younger age groups (Table 2.2).

Table 2.2: Physical activity recommendations for children & young adults (11-21 years).

Authors	Mode	Frequency	Intensity	Duration
ACSM (1990) (adults)	large muscle, rhythmical aerobic activities	3-5 days/week	50-85% max. functional capacity	15-60 mins of continuous or discontinuous aerobic activity
AHA (1990) (adults)	large muscle dynamic movement	3 or more days/week	50-60% max. aerobic capacity	20-30 mins
Sallis & Patrick (1994) (11-21 years)	whole body physical activity	i) daily ii) 3 or more sessions	general activity as part of daily living sustained mod-vigorous	30 mins or more accumulated over each day 20 mins or more
Riopel et al (1986)	large muscles, dynamic exercises	3 days/week or every other day	60% max. functional capacity	> 30 mins
Haskell et al (1985)	large muscles, dynamic exercises	3 days/week	moderate to vigorous	30 mins/day in one or more sessions
Rowland (1981)	aerobic activities, large muscle grps	3 days/week	vigorous	30 mins
Pate & Blair, 1978	whole body physical activity	4 days/week	70% max. functional capacity	20-30mins

All of the early recommendations agree that activity should involve large muscle groups in dynamic, aerobic type exercise of 20 to 30 minutes duration and show much similarity to the adult recommendations. With children, many researchers stress the need to encourage the development of active lifestyles that might be carried into and throughout adulthood. This type of approach emphasises the development of skills and the importance of fun (Simons Morton et al, 1987; Riopel et al, 1986; Haskell et al, 1985). Haskell and colleagues (1985) recommended that children's physical activity should promote an interest in, and skills for, active lifestyles as adults, and that positive benefits could be attained through brief bursts of moderate to vigorous physical activity in one or more sessions rather than longer periods of continuous moderate to vigorous activity.

In 1992, an advisory committee composed of leading scientists and representatives from medical societies and government agencies were assembled to develop a consensus statement on physical activity guidelines for adolescents. In June 1993, the committee met in California and details were published in the Pediatric Exercise Journal November 1994 (Sallis & Patrick,1994). The consensus statement guidelines specify that;

> <u>*Guideline 1:*</u> ***All adolescents should be physically active daily, or nearly every day, as part of play, games, sports, work, transportation, recreation, physical education, or planned exercise, in the context of family, school, and community activities.***

> <u>*Guideline 2:*</u> ***Adolescents should engage in three or more sessions per week of activities that last 20 mins or more at a time and that require moderate to vigorous levels of exertion (i.e. activities that require at least as much effort as brisk or fast walking).***

With the first guideline, the committee deliberately avoided quantitative recommendation in view of the lack of substantive evidence to support specific recommendation. It did however voice support for recommendations which stated that the volume of activity should aspire to a minimum of 30 mins of moderate physical activity on most and preferably all, days of the week. This target compares well with those recently set for adults (Health Education Authority, 1995).

It is notable that whilst these are the most recent recommendations to be formulated specifically for children, they are no more prescriptive than the recommendations laid down by Pate and Blair (1978) over 15 years previously. There is a certain shift of emphasis from vigorous to more moderate forms of activity and growing acceptance that sporadic bouts of activity, in addition to regular sustained exercise are important. Nevertheless, despite the growing body of research, we are little closer to obtaining clear and practical guidelines for parents, physical educators or coaches as to the optimal volume of activity necessary to promote growth, and lifelong health and well-being. Admittedly, every child is an individual and will respond to a particular course of exercise in a different manner. Nevertheless it would be invaluable to have the capacity to diagnose more precisely those children who are not engaging in sufficient exercise and who may be jeopardising their health in consequence. Only then can clear intervention programmes be implemented. Whilst research findings indicate that sustained periods of activity of 20 -30 minutes duration may not be typical of children (Sallis et al, 1993; Armstrong et al, 1990; Haskell et al, 1985), it is sustained activity that receives the major focus for activity recommendations. It has still to be determined whether short bursts of activity (5 minutes duration) taken several times as day can have the same benefits as one prolonged bout of activity. At present it is also naively assumed that recommendations will apply equally to males and females without the concept of separate gender specific recommendations having been fully explored.

2.2 ASPECTS OF HEALTH RELATED FITNESS IN CHILDREN AND ADOLESCENTS.

2.2.1 Laboratory Based studies of Peak Oxygen Uptake[1] in Children.

(a) General

In 1938, Sid Robinson published a report from his experimental studies of physical fitness in males aged 6 to 91 years. Owing to the wide age range studied, the number of subjects tested in each age group was small (1 to 12) but the study provides one of the earliest records of laboratory VO_2 peak measures for young boys and adolescents. The study also set a benchmark for research investigating the relationship of VO_2 peak to age. Measured in absolute terms VO_2 peak increased throughout the adolescent years (from 0.98 $l.min^{-1}$ at age 6) reaching a peak during the post adolescent years (3.61 $l.min^{-1}$ at age 17 to 24). Thereafter VO_2 Peak showed a gradual decline, reaching 1.71 $l.min^{-1}$ for men over 70 years of age. When expressed relative to body weight, VO_2 peak was greatest between the ages of 10 to 17 (52.8 $ml.kg.^{-1}min^{-1}$), again decreasing with increase in years to a level of 25.5 $ml.kg^{-1}min^{-1}$ at age 75 (It should be noted that the ninety one year old man, not surprisingly, recorded resting measures only). The broad age range included in the study, (a span of over 85 years) covered by a sample of only 93 subjects limits the extent to which these figures may be regarded as representative of the fitness status of the male population at that time. The sample was inconsistent in its coverage of groups from across the full socio-economic spectrum and it was undoubtedly biased toward fitter individuals, especially in the older age groups.

[1] Peak Oxygen Uptake (VO_2 Peak) is used here in preference to the more traditional term of maximal oxygen uptake (VO_2 max) for referring to aerobic power in children. It is accepted that many children do not show the customary plateau in oxygen uptake with increase in workload (one of the definitional criteria used to indicate the achievement of VO_2 max). Over the past decade, VO_2 peak has been adopted at the more technically correct term of reference (Armstrong & Davies, 1984). For clarity and consistency, the VO_2 Peak term is used within this review even when referring to older studies which may have reported results as VO_2 max.

The trend of VO_2 Peak with age has been supported by more recent studies and reviews (Shvartz and Reibold, 1990; Kemper et al, 1989; Krahenbuhl et al, 1985; Astrand, 1952). In males, VO_2 peak ($l.min^{-1}$) generally shows a steady increase with age reaching levels as high as 3.7 $l.min^{-1}$ around 16 years, and thereafter remaining stable into early adulthood (Kemper et al, 1989). Krahenbuhl et al (1985) and Shvartz and Reibold (1990) specify lower values for the maximum VO_2 peak levels attained (2.5 - 3.5 $l.min^{-1}$) but also suggest that this peak occurs during late adolescence. Peak oxygen uptake (expressed relative to body weight) in adolescent males is generally stable throughout the adolescent years or showing a slight increase, 47 - 54 $ml.kg.^{-1}min^{-1}$ (Shvartz and Reibold, 1990), 45 - 61 $ml.kg.^{-1}$ min^{-1} (Krahenbuhl et al, 1985), 58 - 61 $ml.kg.^{-1}min^{-1}$ (Kemper et al, 1989).

In females, the patterns of VO_2 peak change with age differs to that of adolescent males. Girls show similar increase in VO_2 peak ($l.min^{-1}$) with age during the prepubertal years but this reaches a peak (2.0 - 2.7 $l.min^{-1}$) much earlier than for males somewhere between the ages of 12 and 17 years (Shvartz and Reibold, 1990; Krahenbuhl et al, 1985). As with males, VO_2 peak ($l.min^{-1}$) then shows steady decline with age throughout adult life to an average level of 1.2 - 1.5 $l.min^{-1}$ at 70 years (Shvartz and Reibold, 1990). VO_2 peak expressed relative to body weight tends to reach a peak at an even younger age. Krahenbuhl and co-workers suggest a decline from 52 $ml.Kg.^{-1}min^{-1}$ at age 6 to 40.5 $ml.Kg.^{-1}min^{-1}$ at age 16. Similarly, Shvartz and Reibold (1990) suggest an average peak of 41 - 46 $ml.Kg.^{-1}min^{-1}$ (higher in fitter categories) at age 8/9, declining to 38 - 44 $ml.Kg.^{-1}min^{-1}$ at age 16.

Up to the age of 12 years, male and female children exhibit similar VO_2 peak levels but by age 14 the difference between the sexes is almost 25% with boys having greater aerobic power (Krahenbuhl et al, 1985). By age 16 this difference exceeds 50% as male aerobic capacity continues to increase against the female earlier decline.

With VO_2 peak relative to body weight, the difference between the males and females is estimated to increase from 1.5% at age 6 to 32% at age 16 (Krahenbuhl et al, 1985). The most common explanations for this gender pattern is the development of greater muscle mass in the males and greater fat mass in females following puberty (Krahenbuhl et al, 1985). Krahenbuhl also suggests that differences may be accentuated by gender differences in time spent in moderate to vigorous activities.

Table 2.3 summarises findings from studies conducted over the last 50 years. Most studies are in wide agreement as to expected levels of peak oxygen uptake for the 13 to 14 age group; Boys, 47 - 54 $ml.Kg^{-1}min^{-1}$, girls 39 - 45 $ml.Kg^{-1}min^{-1}$ (Shvartz and Reibold, 1990). Values quoted for children from Scandinavia and the Netherlands (Kemper et al, 1989; Lange Anderson et al, 1976; Astrand, 1952) are higher than those given for other studies. It is difficult however to ascertain whether this is due to differences in the selection procedures, the methodological procedures or a genuine superior level of aerobic fitness in the Nordic children. The low standard deviations quoted from Astrand's early studies suggests that the range of children recruited was limited, and that fatter and less well trained children may have been under represented. Lange Anderson and colleagues (1976) report extremely high levels of aerobic power, particularly for girls, in a sample that was orginally described as representative of a 'typical Norwegian rural inland district' (Lange Anderson et al, 1974). The presence of the fitness survey programme however clearly impacted the activity and fitness levels of the children with physical education and recreational sports provision being considerably improved during the period of study. Only one of the studies listed is based on a representative population sample (Shephard, 1986).

Table 2.3 Reported levels of VO_2 peak in adolescent children 10 - 16 years - Non UK studies

Study	Country	Age (years)	Sex	Mean VO_2 Peak (+/-sd) ($ml.Kg^{-1}min^{-1}$)	Test Protocol
Robinson et al (1938)	U.S.	8-12 13-15	M (n=9) M (n=9)	52.1 47.1	Treadmill
Morse et al (1949)	U.S.	10-12 13-17	M (n=22) M (n=81)	47.8 +/- 5.0 48-51	Treadmill
Astrand (1952)	Scandinavia	10-11 12-13 14-15	M F M F M F	56.1 +/- 3.6 52.4 +/- 2.8 56.5 +/- 2.4 49.8 +/- 2.5 59.9 +/- 2.7 46.0 +/- 3.3	Cycle Ergometer
Seliger et al (1971)	Czecho-slovakia	12&15	M F	43.0 - 52.1 34.9 - 42.2	Cycle Ergometer
Koybayashi et al (1978)	Japan	13 14 15 16	M (n=43)	45.0 +/-5.3 48.0 +/- 5.5 49.1 +/- 4.4 50.2 +/- 3.1	Treadmill
Lange Anderson et al (1974)	Norway	12 14 16	M (n=12) F (n=15) M (n=15) F (n=13) M (n=13) F (n=9)	50.4 +/-7.5 41.9 +/- 5.8 47.2 +/- 8.3 36.9 +/- 4.6 49.3 +/- 7.8 38.4 +/- 4/2	Cycle Ergometer
Lange Anderson et al (1976)	Norway (longitudinal follow-up)	12	M (n=30) F (n=34)	58.0 +/- 8.0 53.6 +/- 6.8	Cycle Ergometer
Lange Anderson et al (1984)	Germany	13-14	M (n=27) F (n=21)	54 +/- 5.62 44 +/- 6.83	Cycle Ergometer
Yoshizawa et al (1986)	Japan	13	M (n=17) F (n=22)	55.6 +/- 7.2 48.4 +/- 5.4	Not Specified
Canada Fitness Survey (Shephard, 1986)	Canada	13-14	M F	50.7 42.5	1 mile run walk *converted to VO_2 Peak by Tuxworth, 1988)*
Binkhorst et al (1986)	Netherlands	14	M (n=22) F (n=23)	51.1 +/- 5.4 44.7 +/- 4.2	Treadmill
Vanden Eynde et al (1988)	Belgium	12-15	M (n=30)	49.6 +/-5.0 to 52.5+/-5.2	Cycle Ergometer
Amsterdam Growth Study, (Kemper et al 1995, 1989)	Amsterdam	13/14	M(n=93) F(n=103)	58 +/- 4.7 to 59 +/- 6.3 51 +/- 6.1	Treadmill

(b) UK studies: Laboratory based VO_2 Peak assessment

There have been only limited laboratory studies of peak oxygen uptake in British children prior to the late 1980's. Most laboratory studies have been reserved for the assessment of fitness standards and training methods for young elite performers (Baxter-Jones & Helms, 1995; The TOYA project, 1992) or were field based investigations (Northern Ireland Fitness Survey, 1989; Watkins et al, 1983; Farrally et al, 1980; Heart Beat Wales Project (Heart Beat Wales, 1992, 1987) all of which employed field tests for the assessment of physical fitness components rather than the more readily comparable standardised laboratory methods.

One of the earliest studies of VO_2 peak in British children was conducted by Davies and colleagues in London (1972). Ninety two boys and girls aged 6 to 16 performed a stationary cycle ergometer test to exhaustion. Reported mean VO_2 peak across the age group ranged from 1.19 $l.min^{-1}$ to 3.06 $l.min^{-1}$ for boys and 0.98 to 2.11 $l.min^{-1}$ for girls, increasing throughout the adolescent years. No measure of VO_2 peak relative to body weight was cited. Brooke and colleagues (1975) and Thomasson & Hardman (1977) both conducted studies of VO_2 peak in young girls and both reported similar but extremely low levels of VO_2 Peak (34 $ml.kg.^{-1}min^{-1}$). Small sample size (n=8) may account for the poor levels achieved in the former study but the findings of the latter investigation are surprising given that with a reported drop out rate of 25% the sample should have resulted in the sample showing considerable bias toward fitter individuals. Motivation levels in this sample of girls may have been lower, the test protocol indicates that the children were not urged to push themselves to exhaustion and it is likely that many stopped the test before actually reaching their maximal limits. In a later study, Bale (1981, 1978) examined VO_2 peak levels in both boys and girls (first at 11 years, then following them up at 16 years). His findings were in agreement with studies from America and Europe, showing children to have comparable aerobic power up to puberty, but thereafter, boys had higher VO_2 peak levels than their female counterparts. Table 2.4 shows a summary of VO_2 peak levels from those British studies (mid 1970's to present).

Towards the latter end of the 80's, extensive work was carried out by Armstrong et al (1991, 1990, 1989) providing more recent data on standards of VO_2 peak of children in England (11 to 16 years). Again supporting the findings from earlier European studies, Armstrong identified that peak oxygen uptake in children was greater in boys than girls whether expressed in absolute form or relative to body weight (Armstrong et al, 1991, 1990). Mean VO_2 peak for boys was 48-49 $ml.kg.^{-1}min^{-1}$ compared to 39 - 41 $ml.kg.^{-1}min^{-1}$ for girls. Patterns of VO_2 peak change across the age range (11 -16 years) was unfortunately not examined. There is an extensive and international body of evidence reporting a significant gender difference in VO_2 peak after puberty. This difference may be attributed to the higher fat content in post pubertal females leading to reduced lean mass percentage and lower oxygen carrying capacity per unit body mass. None of the studies however have been able to identify whether the measured difference between males and females is an acceptable one. Lifestyle factors such a lower physical activity of girls will also account for some of the gender difference and it may be the many girls are under performing.

As can be seen from Table 2.4 there is little evidence to suggest that the VO_2 peak levels of adolescents has declined over the past decade and this view is supported by several authors (Livingstone, 1994; Armstrong, 1990). Unfortunately no data from British children prior to the early 1970's is available and historical comparison must rely on data from American and European studies. It is notable that the British children do appear to be on the lower end of the normal acceptable range for VO_2 peak.

Table 2.4 Reported levels of VO_2 peak in children 10 - 16 years - UK studies

Study	Country	Age (years)	Sex	Mean VO_2 Peak[2](+/-sd) ($ml.Kg^{-1}min^{-1}$)	Test Protocol
Brooke, (1975)	England	13 -14	F (n=8)	34 (8.5)	Cycle Ergometer
Thomasson & Hardman (1977)	England	12 - 14	F (n=90)	34	Cycle Ergometer
Bale (1978,1981)	England	11 - 12 15 - 16	M (n=25) F (n=25) M (n=10) F (n=9)	40.0 (6.8) 38.9 (6.6) 42.8 (7.4) 35.3 (8.1)	Cycle Ergometer
Farrally et al, (1980)	Scotland	13	M (n=215)	44.5	PWC170 (converted by Tuxworth, '88).
Watkins et al, (1983)	Scotland	13	F (n=347)	39.0	PWC170 (converted by Tuxworth, '88).
Armstrong et al, (1990)	England	11 - 16	M (n=28) F (n=49)	48 +/- 6 39 +/- 5	Treadmill
Armstrong et al, (1990)	England	11 - 16	M (n=57) F (n=62)	42 +/- 5 36 +/- 5	Cycle Ergometer
Armstrong et al, (1991)	England	11 -16	M (n=99) F (n=94)	49 +/- 6 41 +/- 6	Treadmill
Armstrong et al, (1991)	England	11 -16	M (n=100) F (n=70)	43 +/- 6 37 +/- 6	Cycle Ergometer

[2] There is some variation in VO_2 Peak measurement, dependent upon the test protocol adopted. Armstrong (1991, 1990) noted that the mean values for peak oxygen uptake assessed by cycle ergometer tests were on average 11% lower than for those children assessed using a treadmill running protocol. This difference in observed VO_2 peak according to test protocol has been consistently observed in other studies and it is recommended that for studies whereby the VO_2 peak has been determined using a cycle ergometer test, values should be multiplied by a factor of 1.075 (Krahenbuhl et al, 1985). If this strategy is applied to the figures provided in Table 2.4, mean values for the cycle ergometer tests fall more in line with the treadmill determined scores.

2.2.2 Field Based Studies of Health Related Fitness in Children

Laboratory studies of peak oxygen uptake provide a relatively objective and comparative measure of performance capacity. Unfortunately, the requirement of bulky apparatus, expensive equipment and time consuming procedures make the laboratory measures of VO_2 peak unfeasible for large scale epidemiological studies. Most population surveys have thus relied on field based measures of physical fitness, adopting a multi-component test battery. In addition to assessing endurance performance, these batteries are designed to examine wider aspects of fitness, including measures of strength, flexibility, body composition, speed, agility and reaction time. Whilst such an approach helps to gain a broader view of physical fitness in children, it must be accepted that the choice of tests can compromise the validity of findings. Many field measures have not been scientifically validated and few can match laboratory measures in terms of standardisation of procedures.

The United States in particular, has invested much time and money towards establishing health and fitness related norms for American children. The American Alliance for Health, Physical Education, Recreation & Dance (AAHPERD) has co-ordinated an extensive programme of national assessment using a series of field based fitness test batteries devised specially for use in schools (AAHPERD, 1988, 1976, 1965, 1953). These AAHPERD surveys together with results from the National Child and Youth Fitness Survey (NCYFS, Ross & Gilbert, 1985) and the Presidents Council for Physical Fitness and Sport Survey (PCPFS, Reiff et al, 1986) provides a huge volume of data regarding children's fitness spanning over 30 years. Since the first introduction of the tests in 1953, however, the content of the test battery has been altered considerably over the years and opportunity to make comparison between studies has been extremely limited (Corbin & Pangranzi, 1992). Initial tests assessed minimal levels of strength and flexibility, later to be superseded by batteries which looked at aspects of cardiorespiratory endurance, speed, agility and body composition. The later studies placed more focus on health related aspects of fitness and deleted earlier tests which seemed purely skill related e.g. the softball throw and the long jump. This change in emphasis, whilst promoting health related aspects of fitness, reduced the number of performance items that could be reliably monitored across the three decades of testing. Not only had the content of the test batteries been altered, changes in the staff conducting the tests, the test administration and differences in the measurement protocols were all confounding factors likely to make significant contribution to any identified differences in performance over the years of study. The flexed arm hang for girls and the pull up for boys were the only items for which comparable data was available for the full 30 years of investigation.

Following the American example, Canada, (Shephard, 1986, Fitness Canada, 1981) and Australia (Pyke, 1986) have also conducted national surveys of physical fitness in children and in Europe, the Committee for the Development of Sport of the Council of Europe developed it's own physical fitness test battery for use in primary and secondary schools (Eurofit, 1993). The test battery comprises a series of tests of general endurance, local muscular endurance, strength, flexibility, speed and balance including, the PWC170 cycle ergometer test (or the 6 minute timed distance run), the flexed arm hang, the 30 sec speed sit ups test, arm pull or hand grip tests , standing broad jump or vertical jump, sit and reach, plate tapping, 10* 5m shuttle run or 50m sprint, and the Flamingo balance test (Eurofit, 1993). The Eurofit battery has since been used widely in schools throughout Britain, but there has been no endeavour to collate data on a national scale, except in Northern Ireland (NIFS, 89).

One British study which used the AAPHERD test battery to assess physical fitness in over 18,500 children from Britain, Cyprus and America showed favorable results for the British children (Campbell & Pohndorf, 1961). British girls performed better than

American on all tests and British boys were superior to America boys in all tests except for the softball throw (Sloan 1966). As was typical of field studies at this time, inconsistencies in the test procedures and conditions could account for much of the variability between results and whilst the study was a welcome attempt to gain an international perspective on standards of fitness in different national groups, validity of the results is questionable.

Over the 20 years following Campbell and Pohndorf's work there was very little reported study of general health and fitness standards for British children, despite an accumulating body of literature for youth in other countries. This void was tackled by Farrally et al (1980) and Watkins et al (1983) who jointly conducted a series of antropometric and physical fitness tests on groups of boys and girls in Strathclyde. Most of the tests used conformed to the Eurofit test battery. Results indicated that, in general, Scottish children performed less well on the tests compared with reported standards for American and Canadian children. They also performed markedly worse than those British children tested 20 years previously in the Campbell and Pohndorf study. Whilst Farrally and Watkins did express concern that many children exhibited poor levels of cardiorespiratory fitness, they avoided the tempting conclusion that a decline in fitness levels had occurred. The techniques of measurement used in the earlier study were not rigorously standardised and therefore could not offer a comparable set of results. In particular, it was apparent that the Scottish cohort were less practised and less familiar with the battery of tests.

It is evident that whilst the development of multi component field test batteries have been instigated with good intent, with the aim of monitoring standards and highlighting areas of concern, there is limited capacity for comparison between studies and many of the early studies in particular are of tenuous validity. There is obvious subjective preference in regard to which tests are incorporated within the test battery, particularly in regard to selected field tests of aerobic endurance. In America, it has generally been the 1.5 mile run, in Europe the PWC170 test and in Canada, the step test. These tests are not directly comparable and few studies have converted the field test measures to estimated VO_2 peak (due to lack of validity studies for these tests when used with children of wide developmental ages). At best, these national population surveys have been able to demonstrate clear and consistent sex differences in the levels of children's fitness. Typical findings indicate that boys have greater endurance running ability than girls (supporting evidence from laboratory studies of VO_2 peak), are leaner and stronger but score less well on the sit and reach flexibility test (NIFS, 1989; Shephard, 1986; Pyke, 1986; NCYFS, 1985). However, given the inherent differences in the various methodologies employed, and in some cases the considerable sample bias, more detailed comparative analysis is severely restricted. In America, the AAPHERD studies (1984) used a convenience sample (children whose teachers were willing to collect data) and therefore cannot be regarded as representative of the nation as a whole. The NCYFS survey (Ross & Gilbert, 1985) used a national probability sample but whilst participation rates were extremely high (85.6%) there is still a likely bias towards fitter more active children. Beyond the selection procedures, further bias is created by inconsistencies in test administration where factors such as environmental conditions, training of staff and motivation of children will have considerable influence on test results. Tuxworth (1988) highlights how data from surveys conducted in America and Australia (despite using similar measures) is so widely different as to be considered implausible.

Multi-component fitness test batteries, whether used as part of a national assessment programme or simply as part of the school physical education curriculum, are often used in conjunction with tables of age related criterion referenced standards (Cureton & Warren, 1990). This practice, particularly popular in America, has also met with severe criticism (Safrit, 1990; Seefeldt & Vogel, 1989). Few of the targeted levels of 'achievement' are supported by any sound scientific evidence and the arbitrary classification of children into graded levels of performance according to specific (yet unvalidated) fitness/health parameters is of questionable benefit. Furthermore the potential for misclassification of an individual could have serious consequences (Safrit, 1990; Seefeldt & Vogel, 1989; Pate, 1989; Safrit et al, 1988). It is generally agreed that the use of the fitness testing batteries in schools can be extremely beneficial, aiding children to develop their understanding of the principles of exercise training whilst also encouraging desirable fitness behaviours. It has been suggested however that it should be applied and valued as a educational tool not as a scientific measure (Whitehead et al, 1991; Safrit, 1990).

In summary, Britain has lagged behind other nations in regard to implementing a national fitness testing strategy for children. It's lack of action has avoided the problem of launching into large scale initiatives incorporating techniques which are highly likely to become redundant as improved methods of testing are developed but at the same time leaves unanswered the question of just how many children in Britain are compromising their health due to insufficient physical activity and poor physical fitness. The number of children falling within a "low fit" classification band in Britain is a priority research area, particularly in view of the potential implications of low physical fitness and physical activity upon future health. To provide better opportunity to evaluate standards of health related fitness levels in Scottish children priority should be given toward the assessment of aerobic power (VO_2 peak is the only endurance fitness measure that has been rigorously standardised and which offers reliable historic record from previous generations). Given however, that laboratory measures are not feasible within large scale surveys this can only be achieved thorough the development of improved predictive field based tests.

2.3 PHYSICAL ACTIVITY PATTERNS OF CHILDREN AND ADOLESCENTS.

2.3.1 General Overview

As discussed previously, physical activity has four main measurable components, mode, frequency, intensity and duration. No single measure is ideal for assessing all four dimensions of physical activity and researchers have employed a variety of techniques, including self report questionnaires, activity diaries, mechanical counters, continuous heart rate monitors, doubly labelled water and direct observation (Saris, 1985, 1986). Further details of these methods of physical activity assessment are provided in the Review of Methodologies, Chapter 3. The use of so many different measurement devices and techniques makes comparison between studies extremely difficult but over the years a number of consistent findings have emerged from the research.

There is a marked sex difference in children's physical activity levels. Boys appear to be more active than girls from 11 years onwards; an almost universal finding supported by studies in America (YRBS, Pate et al, 1994; Centres for Disease Control, 1992; Aaron et al, 1993; NCYFS, Ross & Gilbert, 1985), Northern Ireland (Livingstone et al, 1992; NIFS, 1989), Germany (Fuchs et al, 1988; Lange Anderson, 1984), Scandinavia (Sunnegarde et al. 1985; Engstrom, 1980), Finland (Telama et al, 1985) and the Netherlands (AGS, 1995). Boys in particular engage in more moderate to vigorous activity than girls and take part in more competitive sports (AGS, 1995; Aaron et al, 1993; Fuchs et al, 1988; Engstrom, 1980). This difference between the sexes is estimated to be as much as 15 to 20% (Sallis, 1993), equivalent to 1-3 hours of moderate to vigorous activity per week (Fuchs et al, 1988; Ross & Gilbert, 1985; Engstrom, 1980) whilst participation in light aerobic activities appears to be similar (AGS, 1995).

There is a steady decline in activity levels from early teens to early 20's, especially in the medium to heavy and heavy forms of exercise (AGS, 1995; Sallis, 1993; Kemper et al, 1989; NIFS, 1989; Fuchs et al, 1988; Telama et al, 1985) and it is more marked as adolescents reach school leaving age (AGS, 1995; Saunders, 1979). The rate of decline in vigorous activity is greater in girls than boys (2.7% for males, 7.4% for females, (Sallis, 1993)) but whilst boys are more inclined to maintain levels of exercise that will benefit cardiovascular fitness at this age, girls show greater tendency to participate in lifetime activities (i.e. activities such as walking, swimming, or dancing that are more readily carried on in adulthood) (NIFS, 1989; NCYFS, 1985). Both groups however show considerable decline in overall activity with the decline in vigorous activity largely due to decline in levels of participation and the decline in moderate activity largely due to a reduction in the average duration of activity bouts (Fuchs et al, 1988).

Due to lack of comparative records, it is unclear whether the decline in activity levels across the adolescent years is a natural aspect of the ageing and development process or is a feature of modern day society. The question of whether children are less active than in previous generations remains speculative. There has been widespread concern that children's lifestyles have become increasingly sedentary and this is supported by findings which indicate increased use of TV, computer and video games during leisure time (Dept of Health, 1995) and a decrease in the number of children who walk to school (Hillman et al, 1993). Alongside this, there has been a noted increase in sports participation compared with previous generations (Brettschneider, 1992; Sunnegarde et al, 1985) but this finding has also been demonstrated in adults (Lee et al, 1992) and is likely due to changes in patterns of recreation and leisure provision within Western societies. Whilst leisure centres, sports clubs and health clubs are becoming increasingly popular outlets for sports and leisure time pursuits, trends in overall activity levels may still be in decline.

One of the earliest studies investigating physical activity patterns in British children was that conducted by Durnin (1971) which examined levels of energy expenditure in groups of Glasgow school children. He found that both boys and girls children spent almost 75 percent of a typical 24 hour day in bed, sitting or standing. A further 10 to 13 % of the time was spent in "standing activity" i.e. light activity involving minor degrees of movement. Boys were more active than girls spending 13% of the day in moderate to vigorous activity (equivalent to 187.2 minutes/day) as opposed to 11 % for the girls (158.4 mins/day). It is notable that this level of participation in moderate to vigorous activity is much higher than estimates reported in more recent studies (Sallis, 1993; Livingstone et al, 1992; Engstrom, 1980).

In the same year as Durnin's study, Bradfield et al (1971) published data regarding the physical activity patterns of obese and non obese children in America. The sample size was small (6 girls in each group) but the study is of interest in that it is one of the earliest studies to use continuous heart rate monitoring as a means to study daily energy expenditure. Heart rate was related to energy expenditure using individually determined regression lines. Both groups spent very little time in moderate to vigorous activities. Sleep and very light activities comprised 70 % of the time spent by obese girls and 71% of the time of non obese girls. Sleep, very light activities and light activities occupied 97% of the time of the obese girls and 99% of the time of non obese girls. No significant difference between the groups in relation to energy expenditure was identified however, it is worthy of note that the reported typical activity levels of obese pupils comprised less than 1% of the 24 hour period compared with 3% for the non-obese group. Whilst seemingly minimal when expressed as a percentage, a difference of 2% per day is actually a difference of almost 30 minutes of moderate to vigorous activity and is therefore quite substantial.

Table 2.5 summarises a number of studies where children's activity levels have been quantified in terms of intensity and time and where it has been possible to translate the results to a minute per day measure. As can been seen, the variance in reported estimates of physical activity levels is enormous. To date there has been no clear guidelines to researchers as to procedures for physical activity classification and there is little agreement between studies as to how "moderate to vigorous activity" has been quantified. Studies examining physical activity patterns by means of questionnaire have tended to attempt to identify time spent in light, moderate and vigorous levels of activity but specific definition of these categories has varied widely between researchers. Under the stratification of activities adopted by Sunnegarde and colleagues (1985), "moderate level" activities included "scouting, walking the dog, fishing, indoor games, being at the youth centre, and taking part in theatricals". Clearly during much of these so called "activities" children could have considerable periods of time during which they were extremely inactive. Likewise, the NCYFS (1985) determined the total time of sports/activity sessions during which children had opportunity for activity, but given that it is highly unlikely that children were active for the entire duration of a session, activity levels can be grossly overestimated by this method (Parcel et al, 1987). The questionnaire surveys show weakest credibility. Children are notoriously unreliable at reporting their own activity (Sallis, 1991; Saris, 1985; Johnson & Foley, 1984), they are less competent than adults at making accurate judgement of time (Sallis, 1991) and have limited capacity for accurate recall of even recent events (Johnson & Foley, 1984). Questionnaires which have examined activity participation and levels over the past year (Aaron et al, 1993) may thus reflect the cognitive abilities of the children rather than give clear and accurate index of actual physical activity.

Studies using objective physiological measures of activity (heart rate monitoring, doubly labelled water, motion sensors) have shown better agreement within the research findings. On average, children appear to engage in 30 to 60 minutes of moderate to vigorous activity per day with levels being lower for girls compared with boys (Sallis et al, 1993; Livingstone et al, 1992; Armstrong et al, 1991). Even however using these more objective techniques the classification of moderate to vigorous activity varies between studies and many researchers have adopted different criteria for the identification of active periods. Some studies, having conducted laboratory treadmill tests and established the heart rate/oxygen uptake relationship for each individual, have been able to identify moderate to vigorous activity relative to peak oxygen uptake (Livingstone et al, 1992; Riddoch et al, 1991b; Verchuur & Kemper, 1985). Others have simply examined heart rate relative to a general cut off score (Sallis et al, 1993; Armstrong et al, 1991; 1990) but the value selected is not always consistent between studies. In one study (Armstrong et al, 1991) moderate activity was identified as any activity where heart rate was sustained above 139 $b.min^{-1}$, others however have found this level too high and have elected to use 119 $b.min^{-1}$ (Sallis et al, 1993; Durant et al, 1992) and within a general review of physical activity studies, Pate and colleagues (1994) interpreted data from Armstrong's study as vigorous level activity.

The selected duration for identifying active periods has also varied. It is possible to examine the total number (or percentage) of active minutes across the day (Sallis et al, 1993; Durant 1993, 1992) or according to the number of sustained bouts of activity (Sallis et al, 1993; Durant et al, 1993; Armstrong et al, 1991, 1990). Typically the selected duration has been 5, 10 and 20 minute periods. Little research has been conducted to justify the selection of these specific durations of activity bouts and it is unclear to what extent the various arbitrary heart rate "cut off" points are comparable.

Table 2.5: Time spent in moderate to vigorous activity for children 11-16 years.

Researchers	Age (yrs)	Measure & Criteria	Activity Level [3] (mins/day)	
			Males	Females
Durnin (1971)	14	Food intake & energy expenditure	183	155
Engstrom (1980)	15	Questionnaire Mod - vig activity:-	41	28
NCYFS Ross & Gilbert (1985)	10-18	Questionnaire Leisure Time Activity:-	114	103
Sunnegarde et al (1985)		Questionnaire Moderate activity:- Vigorous activity:- Physical Training:-	180 120 18-21	180 90 16
Fuchs et al (1988)	12-13	Questionnaire Sports participation:-	60	54
Forth Valley Health & Fitness Study (1993)	14	Questionnaire Total Activity:- Sports Activity:-	136 87	66 33
Aaron et al (1993)	12-15	Questionnaire Leisure time activity:-	193	57
Amsterdam Growth Study (1995)	13	Structured Interview Total activity Light activity (4 -7 Mets) :- Mod. activity (7-10 Mets) Heavy activity (>10 Mets):-	90 40 32 20	78 42 32 3
Verchuur & Kemper. (1985)	12-14	Heart rate monitoring > 50% VO_2peak	78	60-72
Riddoch et al (1991b)	11-16	Heart rate monitoring >50% VO_2 peak	24	17
Livingstone et al (1992)	12-15	Heart rate monitoring > 50% VO_2peak	52	15
Janz et al, (1992)	6-17	Heart rate monitoring >60% heart rate reserve Prepubescent Pubescent Post pubescent	24 11 2	29 8 8
Armstrong et al (1990)	11-16	Heart rate monitoring >139 $b.min^{-1}$(weekdays):- >139 $b.min^{-1}$(weekdays):-	45 42	33 19
Sallis et al (1993)	11-16	Heart rate monitoring >119 $b.min^{-1}$ >139 $b.min^{-1}$	63-114 23-35	43-106 11-30

[3] Some researchers report results in terms of weekly averages (Amsterdam Growth Survey, 1995; Forth Valley Fitness Survey, 1993). For the purposes of comparison, these have been converted to a minutes per day measure.

With the lack of standardised procedures and analytical method it has not been feasible to establish reliable normative standards. Researchers have reached a point where they can reliably quantify physical activity using physiological indicators but appear to be undecided as to how best to interpret that data. As yet it is unclear what level of inactivity constitutes a serious risk to health and without that knowledge it is impossible to determine precisely how many children are "at risk". The preferred approach at present is to make use of the recent recommendations for children activity (Sallis & Patrick, 1994) and to examine the percentage of children fulfilling these guidelines.

Armstrong and colleagues (1991, 1990, 1989) concluded from their extensive study of fitness and physical activity patterns in English adolescents that "children are fit but not active". With no previous quantitative record of physical activity levels however, the conclusion was based on a value judgement of "appropriate levels of activity for children". The methods used to assess activity levels from continuous heart rate data may also have been misleading given that only relatively high levels of activity were examined and that results were based on only 3 to 4 days of measurement (Armstrong et al, 1991, 1990). Other reports indicate that compared with adults, children are the most active sector of the population (Pate et al, 1994; Freedson & Rowland, 1992; Sallis & McKenzie, 1991). In one of the most comprehensive and detailed reviews of physical activity in children, Pate and colleagues (1994) estimated that most children (greater than 80%) meet the current consensus guidelines regarding daily participation in sports and physical activities and that on average levels amount to approximately one hour per day. Reported standards for adult populations are considerably worse (ADNFS, 1992).

Children's participation in sustained moderate to vigorous activity may be less encouraging. Pate and colleagues review (1994) identified that on average, only 50%

of children achieve the second consensus recommendation for participation in 3 or more sustained 20 minute sessions over one week. No studies have examined the extent to which Scottish children meet these recommendations. The best available evidence at present is from the national survey of health behaviours in Scottish children (Currie & Todd, 1990) which found that over half the children studied, 11-15 years, reported engaging in moderate to vigorous exercise outside of school, 4 to 7 times a week. Since these figures are based on children's self report of behaviours they may be somewhat exaggerated, nevertheless a significant number of children appear to be very active with approximately one fifth of all children reporting involvement in daily 'out of school' activity in addition to their regular school PE and games (Boys, 31%; Girls, 14%). The study also identified a considerable number of children who reported very low levels of participation in 'out of school' activity (once a week or less) with sedentary behaviours again being particularly prominent in girls (32% girls, 19% boys).

2.3.2 Mode of Activity

Mode of activity is important in that it gives an indication of the types of activities children are choosing to undertake. It may also give an indication of the settings and opportunities for participation in activity (eg. PE classes, school breaks, after school, evening youth club and so on). This type of information is most commonly obtained from questionnaire surveys, direct observation and/or activity diaries (Saris, 1985).

Results from the Northern Ireland Fitness Survey indicate that for most children, 11 - 18 years, sport is their favourite activity during leisure time although this is much more true for boys than girls. Forty one percent of boys and 23% of girls held sport as their favourite leisure time activity ahead of watching TV (13% boys, 17% girls), although in the case of girls, chatting with friends was equally popular (23%), (NIFS, 1989). The most popular activities reported for boys were football followed by basketball, swimming, gaelic football and running and for girls, swimming, badminton, netball, hockey and volleyball (NIFS,1989). A similar pattern of participation is shown for Scottish children where ranking in order of children participating in sports after school is, for girls; swimming, cycling, badminton, dance and aerobics/keep fit; and for boys, football, cycling, swimming, golf and badminton (FVFS, 1993). Results from the National Child Youth Fitness Survey (Ross & Gilbert, 1985) indicate that the dominant activities for American boys were (in descending order of popularity) bicycling, basketball, football, baseball/softball and swimming; and for American girls, swimming, bicycling, dancing, roller-skating and walking. In Finland, jogging/running is reported as the most popular activity for both boys and girls followed by cycling, walking and cross-country skiing for girls and ice-hockey, cycling, football and cross country skiing for boys (Telama et al, 1985).

These findings must all be weighed up with careful consideration of regional and national differences. Nevertheless, swimming appears the one activity that is frequently engaged in by both males and females, and is popular across a wide age range. Another study of Scottish school children (Hendry et al, 1989) found that swimming was the most popular sport over the entire age range 11 - 20 and for both sexes. Whilst badminton and squash were also equally favoured by boys and girls, other sports showed more gender discrimination. Rugby, football, cricket and circuit training were predominantly male sports and dance, keep fit and aerobics predominantly female. Most sports showed a decline in participation with the one exception being keep fit/aerobics where participation by older girls was high (38%).

The Northern Ireland fitness survey (1989), the (Scottish) Young Peoples Leisure and Lifestyles Project (Hendry et al, 1989), the Central Region & Forth Valley

Health Board Fitness Study (1993), the Sports Council for Wales Review (1989) and a large study of health related behaviours in English secondary school children (Balding, 1988) have all found that football was the most popular extra curricular activity for boys. Around 60% of adolescent boys play football on a regular weekly basis but participation tends to fall as boys progress through school. Balding (1988) reported that whereas 58.6% of first year boys played football regularly, this figure dropped to 41.8% by fifth year. This decline in participation is also evident for other popular team games such as rugby, hockey and netball.

2.3.3 Physical Activity in Physical Education

Physical education in schools plays a key role in introducing new sports and activities to children, helping them to develop important motor skills, and ideally promoting a sense of fun and enjoyment in physical activity and setting the foundations for continuing participation in activity throughout adulthood. Over a typical school year children may be given the opportunity to try over 20 different sports and activities (Sharp, 1990, PEA, 1987; NCYFS, Ross & Gilbert, 1985) and much focus is placed upon helping children develop the necessary skills to participate and enjoy a wide variety of popular activities. Given that curriculum PE may be offered over 2 to 5 days per week and that it may introduce many children to new sports and activities, school based activity can make a considerable contribution to children's overall activity both during the school years and beyond.

It is of major concern that time for physical education has dropped since the early ninety eighties. Armstrong and McManus (1994) point out that less time is devoted to physical education in British secondary schools than in most other European countries and that in 1994, a staggering 71% of state school children were spending less that the recommended minimum of 2 hours per week in physical education (SHA, 1991). Curriculum guidelines in Scotland recommend a minimum of 80 hours physical education over years 3 and 4 (Scottish Consultative Council on the Curriculum, 1989). This level, based on 33 weeks of school per year, is equivalent to approximately 72 mins/week. The Forth Valley Fitness Survey (1993) reports an average of 119-141 mins/week in schools in the Central Region, split between 2.7 - 2.9 periods per week. Another study of schooling across Scotland reports the following PE times; (121-128 mins/week in years 1&2; 88-234 mins/week in years 3 & 4 and 61-204 mins/week in year 5 (Sharp, 1990). Most schools at present thus manage to offer more PE time than the recommended minimum level but for many, the time allocated to physical education may be gradually being depleted (Sharp, 1990). The reported figures in particular indicate wide variance in PE provision between schools and for the older year groups PE may be an optional subject.

The decline in physical education time is of immense concern, especially since PE time cannot be wholly devoted to "activity time". Parcel and co-workers (1987) report that only 20% of the typical PE class is devoted to activities that can be categorised as "moderate to vigorous physical activity" (Simons Morton, 1987; Bar Or, 1987) and results from the Northern Ireland Fitness Survey report that only 20% of boys and 10% of girls regularly get out of breath during PE and games classes. It is unavoidable that changing and showering must occupy time at the start and end of each lesson and teachers must allow time for organisation, teaching and skill development as well promoting fitness. Parcel and colleagues (1987) have found that many children may actually be more active during school recreation than during school PE and this may be particularly true for primary age children for which school breaks may be the most active period of the day (Payne, 1995, personal communication). The majority of secondary school children however do not appear to be active during school recreational breaks (NIFS, 1989) and for many school physical education may be their only opportunity for activity. For children in Northern Ireland it has been reported that 20% of boys and 30% of girls, did no exercise outside of compulsory PE and games and twice as many older girls as younger girls took no exercise outside of PE and Games lessons (NIFS, 1989). A report by the Scottish Sports Council estimates that 43% of all children's activities are undertaken through school (Scottish Sports Council, 1993). It is worrying therefore that in many Scottish schools the time for PE has decreased over the years and that in almost 5% of schools it is possible for pupils not to take any physical education beyond year 2 (Sharp,1990). Tuxworth (1988) puts the volume of PE provision in school into perspective:

> *"For many children, exposure to professionally taught PE may be only two, 25 minute (allowing for 10 minutes for changing) periods of activity a week for 3 to 4 years (40 weeks per year) - about 120 hours within some 10 000 - 12 000 hours of schooling. In turn these occupy the 65 000 to 70 000 waking hours of the life of a child of ages 5 to 16 - 18 years."* (Tuxworth, 1988)

If the proposal that the volume of moderate to vigorous physical activity within a physical education class may be only 20 % of total PE class time is considered, the picture is even more grim. Were a child to only engage in activity during a compulsory PE class they would manage to spend only 35-50 hours of their 65 000 to 70 000 waking hours between the ages of 5 to 16 - 18 years in moderate to vigorous activity (as little as 2 days over a 12 year span). To what extent this is reality for some children is unclear. Further work is necessary to establish just how many Scottish children are currently failing to meet current guidelines for participation in activity and to establish the contribution of both school and non school activities in children's participation.

CHAPTER 3

REVIEW OF METHODOLOGIES

3.1 THE ASSESSMENT OF PEAK OXYGEN UPTAKE

3.1.1 Direct measurement of peak oxygen uptake

Aerobic fitness refers to the body's ability to take in, transport and utilise oxygen for energy production (Sharkey, 1991). Aerobic metabolism is the principle source of energy for most daily activities, from household chores to recreational sports and therefore sustains a wide range of activities of varied type, intensity and duration. As such, the potential measurable/performance outcome of "aerobic fitness", whether applied to sporting performance or general health and well-being, is extremely diverse. Physical exertion, whether of 5 minutes or many hours duration, relies principally on aerobic metabolism and one test can not adequately describe the body's capacity for this wide spectrum of physical challenges.

Despite this, a single test has however prevailed throughout the history of aerobic fitness assessment. In the early 1920's Hill and Lupton (1923) identified that each person has a maximal level of oxygen consumption and that this measure can provide a good indicator of relative aerobic capacity. The test of "maximal oxygen uptake" (VO_2max) has been carefully standardised over the decades and even today it is largely regarded as one of the best single indexes of cardiorespiratory function and the body's capacity for aerobic metabolism (Armstrong, 1990, 1988; Astrand & Rodahl, 1986, Krahenbuhl et al, 1985). Other tests have been developed for the assessment of endurance performance such as lactate threshold, onset of blood lactate accumulation, and ventilatory threshold but their relationship to health parameters has not been studied extensively nor procedures fully standardised (Sharkey, 1991).

Maximal oxygen uptake is defined as the maximum rate at which an individual can take up and utilise oxygen whilst breathing air at sea level (BASS Position Statement, Hale et al, 1988). As such it provides an overall measure of the efficiency of the lungs, heart, blood, and muscle cells, (the constituent parts of the aerobic system) to take up and utilise oxygen for energy production. It provides a measure of cardiopulmonary reserve and can be used as an indicator of an individuals capacity to engage in sustained activity.

"Over the years, fitness has been defined and measured in many ways, but none has been so pervasive and influential as the definition that has dominated the last several decades and defines aerobic fitness (aerobic power or capacity) with the maximal oxygen uptake VO_2max. This definition is the criterion used to validate all aerobic fitness tests; it is the score used to measure change in aerobic fitness training studies; it is thought to be highly related to performance in work and sport; and it is widely believed to be related to health and a reduced risk of heart disease. In short, it has become one of the most frequently used measurements in exercise physiology."

(Sharkey, 1991, p1-2)

Sharkey emphasises that popularity alone does not justify employment and that, VO_2max must be used and interpreted with care. It is a highly specific measure and must not be attributed with global qualities. It should be remembered that it may not necessarily be the best measure of all types of endurance performance and equally it may not be the most important measure of health related fitness. The "best" measures however have yet to be identified and VO_2max is the one measure that can provide highly reliable and comparable results. Until measures specific to particular domains of aerobic fitness are devised and validated and these measures are scientifically proven to have stronger correlations with certain endurance events or particular health related outcomes, the VO_2max measure is likely to remain a dominant feature in health and performance related research.

Assessment of VO_2max is carried out under laboratory conditions. Subjects are taken to volitional exhaustion during an incremental exercise test on a treadmill or cycle ergometer. Most commonly the tests are designed using progressive workloads of 2/3 minutes duration with the intensity of the workloads set so as to bring the subject to exhaustion after 10 to 15 minutes (Rowland, 1993; Astrand & Rodahl, 1986). The volume and composition of the expired gases are collected and analysed throughout the test. Strict criteria (based on both subjective and objective physiological indicators) are used to determine whether or not maximal effort has been attained. These include; a plateau in oxygen uptake despite increase in workload, a respiratory quotient greater than unity, a heart rate at peak exercise greater than 95% of the predicted maximal heart rate for age, a high rating of perceived exertion, sweating, facial flushing, dyspnea, loss of technique, and faltering gait (Rivera Brown et al, 1992; Myers et al, 1990). This, along with established test protocols which promote carefully standardised procedures and environmental conditions, makes the VO_2max test a highly accurate, comparable and reproducible measure. It is heavily dependent on subject motivation to exercise to exhaustion but the use of definitional criteria, as indicated above, ensures that erroneous data can be identified and discounted.

Maximal oxygen uptake has been used to assess aerobic fitness in both adults (Hale et al, 1988) and children (Freedson & Goodman, 1993). Many studies, however, have indicated that children often do not show the customary plateau in oxygen uptake towards the end of the test (one of the criteria for determining whether VO_2 max has been attained) (Freedson & Goodman, 1993; Rowland, 1993; Rivera Brown et al, 1992; Buono et al, 1991; Shephard et al, 1971). The presence or absence of a plateau in oxygen uptake appears to be independent of subject effort, aerobic fitness or non-aerobic factors and it's use as a criterion measure in children cannot be recommended (Rowland,1989). This problem has been circumnavigated by the introduction of the term peak oxygen uptake (VO_2 Peak) and VO_2 Peak is now generally recommended as the more appropriate term when referring to aerobic power in children.

Freedson and Goodman (1993) reviewed several studies of the test retest reliability of the VO_2 Peak test in children,10 to 17 years. The use of both walking and running treadmill protocols in addition to cycle ergometer tests was investigated. Whilst, reported reliability coefficients for VO_2 Peak (ml.Kg.$^{-1}$min^{-1}) using the treadmill walking protocol were low, r=0.47 (Paterson et al, 1981), reliability coefficients for the treadmill running and cycle ergometer protocols ranged from r=0.53 up to r=0.99. Most studies reported test retest correlations of 0.81 and above. It was concluded that the VO_2 Peak test could offer a reliable measure of cardiovascular fitness subject to the mode of exercise and protocol used. Treadmill running protocols were recommended (Freedson & Goodman, 1993).

3.1.2 Sub-maximal tests and field tests of aerobic fitness

Whilst the direct measurement of VO_2 Peak appears to provide a reasonably valid and reproducible measure and the existence of normative data for VO_2 Peak in children (Shvartz and Reibold, 1990; Krahenbuhl et al, 1985; Bar-Or, 1983) make it an attractive measure in terms of enabling some comparative analysis between studies, reservations remain regarding it's appropriateness for community based and large survey based studies. Its main disadvantage is the requirement of expensive laboratory facilities and individual testing. It is an extremely time consuming and labour intensive test. The high degree of commitment demanded of the individual in terms of visiting the laboratory, and accepting the discomfort of a maximal exercise test is likely to result in limited sample recruitment. As an alternative, a number of field tests and sub-maximal tests have been devised in attempt to alleviate the problems associated with direct measurement of oxygen consumption. Cycle ergometer tests, step tests, walk/run tests are among the most commonly used (Astrand & Rodahl, 1986). Practically all submaximal tests carry a percentage error, estimated at 15% (Astrand & Rodahl, 1986; Coleman, 1976) and the relative merits and disadvantages of respective tests must be weighed carefully.

Cycle Ergometer Tests: Tests such as the Astrand Ryhming, cycle ergometer test are particularly popular for the assessment of adults in community and occupational health settings. The test is based on heart rate response to a steady state bout of exercise, from which maximal oxygen uptake may be determined due to the known linear relationship between heart rate, oxygen uptake and workload (Astrand & Rodahl, 1986). The test is quick (3-6 minutes), easy to administer and, as it is submaximal, most individuals can complete the test safely irrespective of fitness. By substituting the final workload and the corresponding steady state heart rate into a carefully devised nomogram a quick estimate of maximal oxygen uptake is provided. Correction factors may be used to adjust the predicted VO_2max value for the effects of age, gender, and/or body size (Astrand & Rodahl, 1986) but these correctional tables only extend to subjects aged 15 to 65 and therefore application of the test to child populations is limited. Whilst various modifications of the nomogram have been proposed since Astrand and Ryhming first introduced it (Storer et al, 1990; Siconolfi et al, 1982), only one of the prediction equations developed is applicable to young adolescents (Buono et al, 1989). Initial results seem promising (correlation between estimated and measured VO_2 peak, r=0.89, SEE=12%), but further validation is required.

One submaximal cycle ergometer test which has been used more widely, and more sucessfully, for fitness assessment in children (Eurofit, 1993; Farrally et al, 1983; Watkins et al, 1980) is the Physical Work Capacity test, PWC170, (Wahlund, 1948). Contrary to other cycle ergometer tests, it was not specifically devised to predict maximal oxygen uptake, but to provide an indicator of an individuals work capacity at submaximal levels. Correlations with maximal oxygen uptake are notably poor (Strandell, 1964). Since it is unusual to perform activities requiring maximal effort in day to day living, however, the PWC170 test arguably provides a better indicator of an individuals capacity to perform regular daily activities.

The procedures are well standardised and easy to administer. Subjects are required to pedal a cycle ergometer for 6 minutes at a set rate against a number of increasing workloads. With heart rate monitored throughout the test and recorded during the final 5 seconds of each stage, the workload corresponding to a heart rate of 170 can be determined graphically by extrapolation or interpolation from the final two workloads and heart rate. It is a popular test for the assessment of endurance capacity in children but as with other cycle ergometer tests, the PWC170 test must assume relatively small individual variation in mechanical efficiency between subjects. Such an assumption may be legitimate for the testing of athletic populations but may constitute a major error in the testing of subjects unfamiliar with cycling techniques. Mahoney (1992) found the PWC170 to be a less valid test of maximal oxygen uptake in non-caucasian children in the UK, and attributed this finding to differences in cultural and social background. Many of the girls in particular, had never ridden a bike and had difficulty at pedalling at the required frequency. In view of this, the test may be unsuitable for samples where the cycling proficiency is unknown.

Step tests: The Harvard step test was developed for the purpose of testing endurance capacity in young adults signing up with the US military (Brouha et al, 1943). A variety of test protocols have been employed but the common element in all has been that the subject is required to step on and off a specially constructed bench and maximal oxygen uptake measured directly during the test or predicted from heart rate recovery (Astrand & Rodahl, 1986; Kasch et al, 1966; Nagle et al, 1965). The test offers a less expensive alternative to the cycle ergometer, can be used in conjunction with the Astrand Ryhming nomogram in adults (Astrand & Rodahl, 1986) and as several people may be tested at one time it is ideal for testing larger groups. Unfortunately it is not an easily standardised measure, intensity must be varied according to age and fitness level (Astrand & Rodahl, 1986; Ryhming,1953), optimal step height will vary between individuals (especially marked for children of wide maturational age) and performance is easily affected by technique. Shephard, (1966) noted a marked learning effect over repeated step tests, particularly at the faster work rates. Children, in particular, may find difficulty setting the optimal cadence and with larger steps and at faster work rates, risk of injury is increased.

Time/Distance runs: Many time and distance runs have been introduced for the estimation of aerobic power in children. It is assumed that all children are reasonably acquainted with the skills of running and that mechanical efficiency is comparable between individuals of similar age. They are generally maximal tests requiring subjects to run as fast as they can across a set distance or as far as they can within a set time. The Cooper 12 min run/walk test is particularly popular within schools (Cooper, 1968) but 5,6, 9 and 15 minute runs, and 300 yard to 1.5 mile runs have also been used (MacNaughton et al, 1990; Eston & Brodie, 1985; van Mechelen et al, 1986). Unfortunately whilst all the tests are extremely simple and easy to administer, test validity is severely compromised. Since most are run on outdoor tracks, it is difficult to standardise the test conditions; performance can be influenced by the weather conditions, the quality of the running surface can be variable, and subjects, particularly children, often have difficulty pacing themselves for optimal performance. Reported correlations between field running tests and laboratory measures of peak oxygen uptake have varied from 0.22 (Krahenbuhl et al, 1977) to 0.91 (Getchell et al, 1977) (both reported in Eston and Brodie, 1985). In a recent study (Turley et al, 1994), the correlation between two consecutive 9 minute run times with VO_2 Peak determined by a peak cycle ergometer test were relatively weak (r=0.62 and r=0.64 respectively) and when data was separated by gender groups, correlations were considerably lower for females (r=0.56 and r=0.48) compared with males (r=0.65 and r=0.71).

The 20 metre shuttle run test: The 20 metre shuttle run test, first devised for adults (Leger and Lambert, 1982) and later modified for children (Leger et al, 1988) is a field based running test for the prediction of VO_2max/ VO_2 Peak. Like the VO_2 Peak test, it is a maximal test, using progressive incremental stages and set at a level that test duration is approximately 6-15 minutes. Subjects are required to run back and forth along a marked 20m shuttle run in time to an audio signal played on a pre-recorded tape and performance is assessed by the maximal running speed attained (Leger et al, 1988) or by the number of laps attained (Boreham et al, 1990).

It has been shown to be a reliable and valid test of maximal oxygen uptake in healthy adults (Ramsbottom et al, 1988; Paliczka et al, 1987; Leger & Lambert, 1982) but, as with other tests, there is less consensus regarding its applicability to child populations. Reported correlations between shuttle run performance and VO_2 Peak in children have varied from r=0.54, n=77 (Armstrong et al, 1988) to r=0.87, n=41 (Boreham et al, 1990). Leger and colleagues (1988) noted that the relationship between shuttle run performance and peak oxygen uptake in children varied significantly with age and their original prediction equations for children actually incorporate an age factor. Maturational factors may be particularly important. Recent studies have found that the validity of the shuttle run test can be improved by the inclusion of skinfold thickness measures in the prediction equations (Barnett et al, 1993; Riddoch et al, 1992) but it is unclear to what extent these findings are gender and/or age specific. Further research is necessary to clarify the nature of the relationship between shuttle run performance and children's physical development.

Whilst the validity of the test in children needs further scientific evaluation, the test, on the whole, presents an attractive option for the assessment of peak oxygen uptake in groups of children. In line with other field tests, it is inexpensive, requires minimal equipment and is quick and easy to administer. It is possible to test a large number of children at same time, and it can be readily integrated into the school sports programme using the available school facilities. The reliability of the shuttle run test has been poorly scrutinised since the original developmental work by Leger and colleagues (1988) but their report of high test-retest reliability ($r=0.89$, $n=139$, $p<0.01$, 1988) is supported by Mahoney (1992) who found a repeat test correlation of 0.73 in males and 0.88 in females ($n=20$, $p<0.01$). By virtue of it's design, the test clearly avoids many of the pitfalls experienced by other field running tests. As it can be conducted in a gymnasium, variance due to environmental variables (e.g. temperature, wind resistance, type of running surface) can be more carefully controlled and standardised and the timed bleep can aid appropriate pacing in subjects unfamiliar with the test. The test has been already used successfully within a large national fitness survey (NIFS, 1989) and techniques and procedures appear to be sufficiently standardised as to enable inter-test comparison.

3.2 THE ASSESSMENT OF PHYSICAL ACTIVITY

"Every type of exercise is, in a sense, a unique situation"

(Astrand & Rodahl, 1986, p383)

The quest for a reliable and valid measure of physical activity is not a modern endeavour. Back in the 15th Century, Leonardo Da Vinci designed a form of pedometer which measured distance by counting steps. Despite a campaign, however, that has spanned centuries and adopted many measurement strategies, the study of physical activity patterns has been hindered by a lack of clarity in definition. Consequently, the development of a valid system of measurement and analysis has remained an elusive objective. The principle concern is that of how to classify and assess physical activity without grossly simplifying the complexities of the action or without remaining so vague as to defeat the aims of definition and be of no scientific merit.

A definition of physical activity has already been provided: - *"any bodily movement produced by the skeletal muscles, that results in energy expenditure"* (Caspersen et al, 1985). With the body consisting of hundreds of different muscle groups, each capable of producing uniquely diverse and graded movement of the body parts, the nature and intensity of any physical activity has infinite possibilities. The scientist must therefore attempt to develop an appropriate system of classification for the interpretation of physical activity patterns which will enhance understanding without over-simplification.

The principle parameters of physical activity are type, intensity, frequency and duration. In any study of physical activity and it's relationship to health and fitness, these factors can not be considered in isolation. It is the sum effect that determines the fitness benefit and the ideal measure should provide information on all four aspects. Numerous and varied methods of physical activity assessment have been developed and systematically reviewed (Saris, 1986b; Laportes et al, 1985; Montoye & Taylor, 1984). Each of the techniques can claim both merits and limitations in their application and the choice of technique depends largely on the nature of the activity to be assessed, the nature of the subjects (sex, age, race), the nature of the sample size, availability of resources, and the desired level of precision.

Direct & Indirect Calorimetry: All energy for human activity is derived from food and ultimately degraded as heat. This basic principle means that physical activity (which by definition results in energy expenditure) can be determined by measurement of heat output of the body and expressed as kcal or kJ per unit time (Durnin & Passmore, 1967). Studies of heat output of the body have shown great ingenuity in methodological design (Atwater & Benedict, 1903; Benedict & Milner, 1907). The human Calorimeter, first devised by Atwater around the turn of the century, entails the subject being placed in a sealed, closed circuit chamber. Heat output is determined by changes in the temperature of water in pipes circulating the chamber and oxygen uptake from the air supply determined. Although it is possible to live in this type of chamber for many days; the essentials (bed, table, food and exercise bike) were generally provided, and extremely accurate measures of energy expenditure may be obtained, the technique somewhat curbs "normal" physical activity. Such great methodological constraints make large population studies unfeasible and the assessment of "normal activity" impossible.

Estimation of energy expenditure may also be made indirectly by the measurement of the body's oxygen consumption. This technique works on the assumption that energy provided by foodstuffs may only be liberated by a series of oxidative processes, which is of course is dependent upon the uptake of oxygen from the air and utilisation in the working muscle. The technique has shown a high level of accuracy with the difference between direct and indirect calorimetry estimates of energy expenditure reported to be less than 2% (Durnin & Passmore, 1967). Unfortunately, the apparatus necessary to collect analyse expired gases from the body tend to be somewhat cumbersome and again, place unacceptable constraints on "normal" activity. Whilst portable systems have been developed and used to good effect to assess O_2 uptake in many common household and sporting activities (Durnin & Passmore, 1967), these systems are definitely portable not pocket- sized. Studies using these devices have required co-operative volunteers with high tolerance of discomfort and the technique is unlikely to be popular with children.

Doubly labelled water: This method, first developed in the nineteen fifties (Lifson, 1955) and validated against both direct and indirect calorimetry (Klein et al, 1984; Westerterp et al, 1984) is often cited as the "gold standard" of physical activity measurement (Livingstone et al, 1992). It provides a highly accurate index of energy expenditure with error estimates ranging from 2 to 10% (Schoeller & Webb, 1984; Schoeller, 1983; Schoeller & Van Santen, 1982) and it causes minimal disruption to normal daily activities. Subjects are simply required to drink a glass of water containing the non-radioactive isotopes Oxygen^{18} and Deuterium (heavy hydrogen)- $2H_2{}^{18}0$. After a period of 12 hours, by which time this water has spread throughout the body, a urine sample is taken and analysed to establish baseline levels of the labelled hydrogen and oxygen. The technique works on the principle that whilst oxygen^{18} is eliminated from body as both carbon dioxide and water, the labelled hydrogen is only eliminated as water. Over the test period, daily activity may continue as normal. So too, will normal bodily function whereby water is continually lost from the body by excretion, exhalation, perspiration and urination. By measuring the extent of hydrogen dilution at the end of the test period, water loss through excretion is indicated. The difference between the actual measured level of oxygen[18] and the level of oxygen[18] that should exist were it only lost as water provides a measure of oxygen [18] lost as CO_2. Oxygen uptake and/or the heat equivalent per mol of expired CO_2 can then be assessed using an estimated respiratory quotient value.

The method causes minimal interference to activity patterns and the only discomfort may be that of providing urine samples at the beginning and end of the test period. Whilst it has been shown to provide a highly reproducible measure and is the main measure of energy expenditure against which all other field tests are compared (Livingstone et al, 1992), the test has two major drawbacks. A primary consideration for large studies is that it is extremely expensive. Secondly, as it only provides a measure of total energy expenditure, it does not give any indications of how activity is patterned across the test period ie. at what times the subject is most active, how intense the activity is or how long it is sustained for. If information regarding the type of activity, duration and/or frequency is required, other measurement tools, such as observation, questionnaire or activity diary also need to be employed.

Movement Counters: Movement counters are of two main types, step counters and accelerometers. They are placed on the waist, wrists or ankles and are based on the principle that most activity involves movement of the torso or the limbs in a vertical direction. The commonest form of step counter is the pedometer. The recording device uses a delicate spring balance, the arm of which deflects downwards on vertical movement. When the intensity of the movement reaches a specified level, a unit of one is recorded. The simplicity of the device is attractive but measurement applications are limited. Intensity of the movement is not indicated and thus the pedometer fails to reflect accurately the differences in energy expenditure at different speeds of walking and running (Saris and Binkhorst, 1977). The design also restricts it's use during activities such as swimming and cycling, both of which are extremely popular pastimes for adolescent children.

Accelerometers measure the acceleration of movement in a vertical direction and therefore can also give an indication of the intensity of the movement. Both mechanical and electronic devices have been developed and were extensively reviewed by Montoye and Taylor (1984). Although test re-test coefficients were high (0.76-0.99) similar limitations to that of the pedometer apply. Montoye et al (1983) devised and tested a new system, the Caltrac Personal Activity Computer (Hemokinetics Inc., Vienna, VA). This device works on the accelerometer principle but uses the recordings to estimate calorific expenditure based on normative data. Comparisons with energy expenditure based on 14 different activities were good and test-retest correlations have been high (Montoye et al, 1983). The validity of this device for monitoring children's activity patterns was later reviewed by Klesges and Klesges (1987). Activity assessed using the Caltrac accelerometer, was compared against observed all day physical activity level. Moderately high but variable Spearman Rank order correlations between hourly readings on the accelerometer and observational systems were identified (0.62 - 0.95). Although significant, the correlation between all day accelerometer readings and observational scores was low (r=0.54). The strength of the correlation appeared to vary according to subject characteristics. Older children, females and overweight (>75th percentile) tended to show higher correlations. In view of these findings, reservations must remain regarding the use of these devices in epidemiological research.

Self Report Measures: Many self report measures of physical activity are available. Recall surveys, activity ratings, standardised written questionnaires, and interviews are all popular forms. There are two main approaches; one is to attempt to gather information regarding the type, frequency and duration of all activities performed over a specified period of time, the other, to get a subjective estimate of typical activity (Lamb & Brodie, 1990). Both methods provide a cheap and simple means of estimating levels of physical activity but the validity and reliability of retrospective subject reports can be dubious. The first method generally involves the use of structured interview or recall survey to assess levels of activity and then estimates energy expenditure from the available physiological data on the energy cost of particular sporting and recreational activities. The required time period over which subject recall of activity patterns can vary from 2 days to 1 year (The British Civil Servants Questionnaire, Alderson & Yasin, 1966; Bouchard Habitual Physical Activity Questionnaire, Bouchard et al, 1983; 7-day Physical Activity Questionnaire, Sallis et al, 1985, The Minnesota Leisure Time Physical Activity Questionnaire, Taylor et al, 1978). Whilst shorter periods are more likely to promote accurate recall, they cannot take account of seasonal variation in exercise participation and ideally have to be repeated throughout the year. Conversely those questionnaires covering longer time spans (several months to 1 year) can allow for seasonal change in activity but are prone to misrepresentation of activity levels due to poor subject recall. In both cases, there can be enormous individual variation in the vigour with which some activities are performed which results in marked divergence between reported activity level and the actual energy expended. The error incorporated in such cases may be considerable and may be accentuated further if subjects also engage in activities for which no normative energy cost data is available. For example, whilst it is easy to obtain a fair estimate of energy expenditure during a 40 minute game of tennis from established records of the average calorific cost of such activity (Brooks & Fahey, 1985), unusual activities which have been less extensively studied may be subject to broader interpretation. In these cases, energy expenditure is often estimated using procedures that are not standardised nor backed up by strong scientific evidence.

The second often simpler type of approach is to gather information regarding "typical" as opposed to "actual" activity (eg. The Framingham Physical Activity Questionnaire, Kannel & Sorlie, 1979; The Godin & Shepard Questionnaire, Godin & Shepard, 1985; Rating of Perceived Activity Level, Forth & Salomi, 1988). This method provides a more general, less quantitative index of relative activity levels and may be more appropriate in large scale epidemiological studies where time and resources may be limited.

Both types of approach have a common problem, namely that they are reliant on subjective reports of behaviour which may be grossly inaccurate. As Lamb and Brodie (1990) highlight "*Whichever option is chosen,.....considerable uncertainty still exists as to the accuracy of self-reported physical activity (Baranowski, 1988), especially where questionnaires demand detailed recall. Moreover, the fundamental problem remaining is how much information on physical activity levels, leisure time or habitual, is actually required in order to study individual or population differences and their associations with health risk factors optimally.*"

There is little available research literature regarding the use of activity questionnaires with children. The majority of questionnaires have been devised for use with adult populations and tend to document occupational and leisure as opposed to school time and leisure activity. Some studies which have examined self report activity measures in children have reported only limited reliability and validity (Baranowski et al, 1984; Forth & Salomi, 1988). Sallis and colleagues (1993) conducted a comparative study of the reliability and validity of three different self report measures in children. The measures selected were, (1) the 7 Day Physical Activity Recall measure (PAR), (2) the Godin-Shephard self administered survey and (3) a simple activity rating. Test retest reliabilities were 0.77, 0.81 and 0.93 respectively. Validity of the 7-Day Recall was determined by comparing recall of vigorous activity with heart rate monitoring records from the same day. A correlation of 0.53 (P<0.001) was obtained for the total group. Effects of gender on physical activity recall were observed with the male subjects being the more reliable reporters. Validity also improved with age. A major problem in all reliability studies concerning physical activity measures is that consistency of the subject response is dependent on consistency of habitual patterns of activity. The two issues are often confused.

Observation methods and activity diaries: An alternative to assessing past or typical activity is to assess ongoing activity and record it as it happens. Such a procedure eliminates the problems associated with poor recall and can be achieved by either using independent assessors to watch and detail subject movements (Klesges et al, 1983) or by getting subjects themselves to record details of their activity within a diary (Riddoch et al, 1992b; Bouchard et al, 1983; Durnin & Passmore, 1967). Observational methods have been employed in attempt to gain more objective information on activity patterns and are often used to validate other activity measures (Klesges & Klesges, 1987; Baranowski et al, 1984). It is however, an extremely time consuming technique. All observers must be carefully trained to ensure standardisation of the activity level criterion, i.e. that they provide consistent and comparable record of subject activity and the data collection itself is a labour intensive task. Keeping track of highly active children can be difficult and activities may often change from one form to another extremely rapidly. In addition there is some concern that the presence of observers may cause inhibition (or exhibition) of "normal" activity (Lamb & Brodie, 1990). Whilst "subject reactivity" to observer presence is well acknowledged it is extremely difficult to quantify the extent to which individual behaviour patterns are actually affected (O'Hara et al, 1989).

Activity diary methods make use of special record sheets covering 1 to 7 days and subjects are asked to provide a written account of their activities over the test period.

This form of activity measure is less invasive than direct observation but does again demand a high level of subject compliance and support. The quality of the information obtained is dependent on the accuracy of the subject in providing a detailed and accurate account of their activity. Validation studies have shown that for most subjects the difference between whole day energy expenditure assessed by diary report and energy expenditure assessed by weighed food intake, is less than 10% (Acheson et al, 1980). However the error range varied considerably (1 to 30 % for most subjects) and for one subject the difference between energy intake and energy expenditure assessed from his activity diary data was as much as 73%. It is essential that diaries are completed diligently and accurately but if this can be achieved, the technique can offer a valid indicator of activity level and energy expenditure (Laporte et al, 1985; Acheson et al, 1980; Edholm et al, 1955).

The activity diary is particularly useful in that it is one of the few methods that can yield valid information regarding **type** of activity. Recall questionnaire, observation and report by proxy can be employed but as mentioned previously these methods have their own limitations. Observation methods are timeconsuming and unsuitable for large studies, recall surveys are of dubious validity in young children particularly if light to moderate, intermittent and/or short duration activity is of interest (Sallis, 1991), questionnaires are often too complex for children compared with the simplicity of a report diary (Thirlaway and Benton, 1993) and report by proxy (typically teacher or parent report) is unsuitable if much activity is undertaken outwith the home or school environment (Ching & Dietz, 1995). Activity diaries clearly present the most viable option for examining type of activity in groups of children in free living conditions. Considerable care must be taken to ensure accurate reporting by subjects but this can be aided by the use of specially designed record sheets along with regular checks on the content of subject reports (Bouchard et al, 1983; Lange Anderson et al, 1978; Durnin & Passmore, 1967; Edholm et al, 1955).

Heart Rate Monitoring: Due to the relationship between heart rate and oxygen consumption during exercise, measurement of heart rate can provide a useful means of estimating energy expenditure. Major advances in the field of micro electronics has enabled the development of sophisticated devices which can detect and store heart rate readings and consequently heart rate monitoring has become an extremely popular method in physical activity studies. It provides a continuous record of activity that reflects both intensity and duration of activity and if conducted over several days can give indication of the frequency of activity bouts and how they are spread across time.

Many types of heart rate monitor are available commercially; telemetric systems, tape recorders and solid state recorders. The most popular of these devices is the telemetry system (Polar Electro Sportstester, PE4000 & PE3000, Finland). It combines the qualities of lightweight, relatively small and non invasive instrumentation with high standards of reliability and validity and has been highly recommended as a research tool for field investigations of heart rate (Leger & Thiverge, 1988). The device consists of a small transmitter which is fixed to the chest by means of belt or electrodes and a small microcomputer receiver which can be worn as a wrist watch. The instruments are capable of recording heart rate every 5, 15 or 60 seconds and can store this data for up to 2.7, 8.3 and 33.7 hours respectively. Telemeter system monitors are of course susceptible to interference from external electronic devices, e.g. televisions, computers and radios and heart rate recordings can be missed, generally due to failure of transmission or momentary loss of electrode contact. These erroneous readings however are generally of negligible levels (1.9 - 2.4 % of total units recorded) (Gretebeck et al, 1991).

Use of the sportstester as a means of measuring heart rate has been validated against ECG recording with adults (Leger & Thivierge, 1988; Karvonen et al, 1984) and also with children in both laboratory and field settings (Treiber et al, 1989; Tsanakas et al, 1986). Furthermore, the use of heart monitors as a means of estimating energy expenditure has been validated against whole body calorimetry (Cessay et al, 1989) and against the doubly labelled water technique (Livingstone et al, 1992).

Energy expenditure can be estimated from heart rate on the basis of the well established linear relationship between heart rate and oxygen uptake during exercise (Astrand & Rodahl, 1986). Due to individual differences in the heart rate/oxygen uptake relationship, individual calibration curves have to be established through laboratory testing where measures of oxygen uptake and heart rate at several work rates are recorded simultaneously. Regression analysis is then applied to develop an equation for predicting oxygen uptake from heart rate specific to that individual and energy expenditure estimated from the predicted levels of oxygen uptake over the measurement period. The technique does have limitations; in particular, the relationship between oxygen uptake is less strong during low level activity and rest (Dauncey & James, 1979) where heart rate may be affected by posture (Christensen et al, 1983; Vokac et al, 1975), and other factors including stress (Bateman et al, 1970), temperature (Sengupta et al, 1979) and fatigue (LeBlanc, 1957). In order to counteract this problem, the use of a "flex heart rate" has been recommended (Payne et al, 1994; Livingstone et al, 1992; Spurr & Reina, 1990; Cessay et al, 1989). This technique involves the identification of a critical heart rate above which the relationship with oxygen uptake becomes linear. Energy expenditure for all values above the flex heart rate is determined in the usual way by means of the individually calibrated regression equations; energy expenditure for those periods where values are below the flex heart rate however is calculated from individually derived values for resting metabolism. Assessment procedures may also have to be adjusted for subjects who engage in a large amount of upper body activity. The heart rate oxygen uptake relationship varies according to the type of activity undertaken, i.e. arm, leg or whole body activity (Vokac et al, 1975). Since this may introduce error into the energy expenditure prediction, the type of activity used to establish calibration curves must be chosen carefully to represent the type of activity to be monitored. Most frequently treadmill walking and running calibration tests are recommended, but if subjects do a lot of upper body work or a large volume of isometric exercise, separate calibration curves specific to that type of activity may be necessary.

As a measure of physical activity, heart rate can be converted to an estimation of energy expenditure or simply expressed in it's crude form i.e. as patterns of heart rate levels. This method is popular for those studies where sample size has been too large to make individual calibration feasible (Armstrong et al, 1991, 1990, 1989) and is a promising techniques for assessing physical activity in the field. There are however problems of data interpretation. The selection of specific heart rate intensity levels or time periods is not a standardised procedure. Different studies adopt different methods of analysis, making cross study comparison difficult and any conclusions drawn from the results must be viewed in light of the fact that all results are subject to the idiosyncrasies of the interpretative method employed.

The number of days of assessment has been widely variable between studies ranging from 1 day (Janz et al, 1992) through to 7 days (Gretebeck & Montoye, 1992). Most popular has been the assessment of 3 to 4 days including monitoring over one weekend day (Livingstone et al, 1992; Armstrong, 1991, 1990). Very few studies however have actually examined how many days are necessary to gain valid estimate of typical activity (Gretebeck & Montoye, 1992). In addition, few studies have adopted comparable techniques for determining the intensity of activity bouts. Most studies have attempted to examine "moderate to vigorous" levels of activity in line with current recommendations (Sallis & Patrick, 1994; ACSM, 1990) but despite this general consensus regarding the type of activity to be assessed, there has been little consistency between studies as to how moderate and vigorous activity has been defined. Those which have conducted individual treadmill calibration tests have reported moderate to vigorous activity as heart rates equivalent to 50%VO_2 peak or above (Livingstone et al, 1992; Riddoch et al, 1991b; Verchuur & Kemper, 1985). Others have examined heart rate relative to a general cut off score, typically 119, 139 and 159 $b.min^{-1}$ (Sallis et al, 1993; Armstrong et al, 1991, 1990). Armstrong and colleagues (1991, 1990) selected heart rate cut off levels of 139 $b.min^{-1}$ and 159 $b.min^{-1}$ to indicate moderate and vigorous activity respectively. This level being based on laboratory studies which indicated that the lower heart rate level was roughly equivalent to brisk walking in children. Other researchers however have found these categories too high and the heart rate cut off of 120 $b.min^{-1}$ is also commonly used (Sallis et al, 1993; Durant et al, 1993, 1992).

The absolute cut off method makes no allowance for individual differences in resting heart rate or heart rate response to exercise and a suggested alternative has been to examine the number of elevated heart rates relative to resting heart rate (Durant et al, 1993, 1992; Washburn & Montoye, 1984) or to a resting heart rate equivalent (Atkins et al, 1995; Janz et al, 1992; Freedson, 1989). Durant and colleagues (1993) examined many different heart rate activity indices (including mean daily heart rate, longest duration of heart rate above a specified level, and the percentage of heart rates 25% and 50% above resting heart rate values (described as the PAHR-25 index and PAHR-50 index respectively). The latter measures were judged to provide the best index of relative physical activity being better able to account for individual differences in fitness status.

Uncertainty remains as to whether it is more important to examine total elevated heart rates or the total number of sustained heart rates. Mean daily heart rate or total heart rates above a selected cut off level have been used (Durant et al, 1993, 1992;

Mueller et al, 1986; Glagov et al, 1970) and whilst mean daily heart rate shows weak relationship with total energy expenditure, the total of elevated heart rates may give good discrimination between patterns of low, medium and high daily physical activity (Mueller et al, 1986). Since isolated heart rate peaks are all included in the analysis (irrespective of duration) it may however be easier for erroneous data to be counted.

Other researchers have examined sustained periods of activity, arguing that it is only prolonged periods of activity (minimum 20 minutes duration) that confers benefit to cardiovascular fitness. However, even with this approach, techniques for identifying sustained periods of activity have varied between researchers. Armstrong and colleagues (1991, 1990) counted intervals of 5, 10 and 20 minute duration with heart rates above 139 and 159 $b.min^{-1}$. Sallis and colleagues (1993) on the other hand counted the total time spent above these levels and allowed for momentary drops in heart rate below the criterion levels provided they were not longer than five minutes. It was argued that this would give a more accurate reflection of the intermittent, sporadic activity typical of children (Sallis et al, 1993). The extent to which the different techniques used by different researchers are comparable has not been examined in detail.

The validity of heart rate monitors as a measure of cardiac activity appears to be high; the validity of heart rate as a measure of physical activity is acceptable. The reliability of heart rate monitors as a measure of cardiac activity is assured but the variability of heart rate as a measure of physical activity is as yet unclear. There is extremely limited research evidence concerning the variability of physical activity across time. Seasonal variation in activity patterns has been identified (Uitenbroek, 1993; Uitenbroek & McQueen, 1992; Shephard et al, 1980) but little is known regarding variation of activity over shorter time periods ie. between months, weeks or days. It will of course be highly dependent on the individual, but the information is essential if a reasonable measure of "typical" activity is to be obtained. The question must arise as to how many days must habitual physical activity be assessed in order to attain accurate reflection of an individual's activity level. What is a "typical" day? Is there such a thing as a "typical" day? It is clear that activity levels must vary from day to day and that the level of variance is different for every individual so how then can the researcher be assured that the days of monitoring chosen will constitute "normal" daily activity? It has already been shown that to assess energy expenditure by food intake that 5 to 7 days of measurement are required (Acheson et al, 1980; Garrow, 1974) but similar practice has not be adopted within heart rate monitoring studies.

Durant and colleagues, 1993, attempted to examine this somewhat neglected aspect of heart rate activity analysis. Between day and within day variability of several heart rate indicators were examined using 131 children aged 5-7 years (Durant et al, 1993) and 159 children aged 3-5 years (Durant et al, 1992). All within day across hour reliabilities were greater than 0.8 but distinct activity components could be identified using mean hourly heart rate and longest duration above 120 $b.min^{-1}$ within each hour. On the basis of these findings it is recommended good practice to record heart rate over the whole day (minimum of 9 hours) and not simply over a limited portion. No significant ethnic, gender, day of the week, or season of the year differences in mean resting heart rate, mean daily heart rate, mean longest duration of the heart rate sustained above 120 $b.min^{-1}$ for the day nor percent of the minutes of daily heart rate above 120 $b.min^{-1}$ were detected. Spearman rank correlation coefficient for heart rate measures from two days of recording, taken 3 to 6 months apart, ranged from 0.65 to 0.66. Using Spearman's prophecy formula to predict the number day recording necessary to gain a correlation of 0.80, it was recommended that over 4 days of recording were required. The study however did not examine variability in activity over weekdays and weekend days. It is likely that more measurement days would be required if weekend activity is also be taken into consideration (given that it may be substantially different from the more structured weekday activity). Only one study has examined heart rate variability across an entire week (Gretebeck & Montoye, 1992) and it has recommended measurement of at least 5 to 6 days, including a weekend day. This level more closely matches the recommendations for energy intake surveys (Acheson et al, 1980, Garrow, 1974) but is not so well adhered to.

No such studies have been conducted in children. Whilst the variability of children's patterns of heart rate activity across a typical week is unclear, general observation suggests that it may be quite considerable and it likely to echo the findings from Gretebeck and Montoye's study of adults (1992). We live in a society that operates in terms of weeks and very often activity is determined by the "weekly schedule" e.g. PE on Tuesday, paper round on Monday to Thursday, video night on Friday, Swim Club on Saturday. It is clear that recording on four consecutive Tuesdays might give a grossly differing result to a recording of four consecutive Fridays. Such a methodology is so obviously flawed that it is unlikely to be implemented, however it does illustrate the problem of random day sampling. Most studies have selected days from within a "normal" week. Numerous four day combinations are possible from within one week and there could potentially be marked variability in the activity levels indicated depending on the combination selected. Further investigation of the fluctuations of heart rate activity levels across weekdays is essential.

In summary, new physical activity guidelines have recently been established for children (Sallis & Patrick, 1994) but little evidence is available to indicate the extent to which these standards are achieved. In particular, there has been a dearth of information regarding the standards of aerobic fitness and physical activity patterns of children in Scotland and how Scottish youth compares with standards in other countries is unclear. More information is required regarding the types of physical activity commonly pursued, how this activity is patterned within children's lifestyles and the likely impact on future health.

Physical activity is a behaviour and shows marked variability between individuals and between days. Whilst day to day variation, weekly variation, seasonal and yearly variation is acknowledged, (Uitenbroek, 1993; Ross & Gilbert, 1985; Shephard et al, 1980), research studies have yet to establish how best to obtain a measure of "typical" activity. Part of the problem is that physical activity may be classified in many ways with as many, if not more, methodologies to match. The lack of standardised criteria for determining sedentary, light, moderate or vigorous activities has resulted in different studies employing different methodologies and different interpretative strategies. The melting pot of measures, methods and populations makes the establishment of clear comparable standards extremely difficult.

It is clear from the evidence that heart rate monitoring can provide a reliable and valid estimate of energy expenditure and physical activity levels. Whilst this technique may be less accurate than techniques such as whole body calorimetry and doubly labelled water, it has the great advantage of being a relatively low cost, non invasive, and easy to use measure; it allows freedom of movement and hence is highly popular with subjects and in addition provides information of both total activity and patterns of activity across the test period. As with many other methods of physical activity assessment, the interpretation of continuous heart rate data is not a carefully standardised procedure. Further work is necessary in order to establish standardised techniques of heart rate analysis. The main issues are regarding the number of days of measurement necessary to gain accurate estimate of typical activity and how best to translate heart rate data into a meaningful measure of light, moderate and/or vigorous activity. There is a need for more thorough evaluation of methods of continuous heart rate measurement and data interpretation.

CHAPTER FOUR

PHASE 1

THE RELIABILITY AND VALIDITY OF THE 20 METRE SHUTTLE RUN TEST AS A PREDICTOR OF PEAK OXYGEN UPTAKE IN EDINBURGH SCHOOL CHILDREN, AGED 13-14 YEARS.

4.1 Introduction

The 20m shuttle run test first devised for adults (Leger & Lambert, 1982) and later modified for children (Leger et al, 1988) is one of the most popular field test of aerobic fitness and is widely used within many British schools today. It has been shown to be a reliable and valid test of maximal oxygen uptake in adults (Ramsbottom et al, 1988, Paliczka et al, 1987; Leger & Lambert, 1982), but reports on its applicability to a child population are equivocal (Barnett et al, 1993; Boreham et al, 1990;Armstrong et al, 1988; Leger et al, 1988). Reported correlations between shuttle run performance and peak oxygen uptake have varied from r=0.54, n=77 (Armstrong et al, 1988) to r=0.87, n=41 (Boreham et al, 1990).

Barnett and colleagues (1993) examined the use of the shuttle test with Hong Kong Chinese students (12-17 years) and found that shuttle run performance as a predictor of VO_2 peak could be improved significantly by including triceps skinfold thickness in the prediction equation (R^2=0.72, n=55, SEE=3.7 ml.Kg.$^{-1}$ min^{-1}). A similar study using Northern Irish students also indicated that skinfold thickness measures could aid prediction of VO_2 peak (Riddoch et al, 1992). For boys, the prediction of VO_2 peak was improved by incorporating the sum of skinfolds along with shuttle run performance (R^2=0.61, n=30), whereas for girls, the relationship between shuttle run performance was weaker and the triceps skinfold thickness alone was a better predictor of VO_2 peak (R^2= 0.71, n=30). The contribution of anthropometric measures to shuttle run performance and hence to the prediction of VO_2 peak in children needs greater clarification. Whether the relationship is similar for children from different cultural groups is also unclear.

Although the validity of the 20m shuttle run test has been addressed by several research investigations (Barnett et al, 1993; Boreham et al, 1990;Armstrong et al, 1988; Leger et al, 1988), its reliability is less well documented. Leger and co-workers (1988) reported a test-retest reliability coefficient of 0.89 for children. It is unclear however, whether one shuttle run is sufficient to gain an accurate representation of a child's maximal aerobic power. Without the benefit of strict physiological criteria, as used for the direct measurement of VO_2 peak in the laboratory, it is difficult to ascertain whether a peak performance is actually recorded. With physiological measures being impractical, and with no appropriate means of determining subject motivation, the test is potentially flawed by its inability to objectively distinguish maximal from non maximal performance. The aims of this study were threefold:

- To examine the reliability of the 20m shuttle run test in 13 to 14 year old children across 3 separate test days
- To examine the validity of the 20m shuttle run test as a predictor of VO_2 peak in 13 to 14 year old children, and
- To determine whether the inclusion of anthropometric variables (height, weight, and skinfold thickness measures) can significantly aid the prediction of VO_2 peak from shuttle run performance[4].

[4] The study was undertaken in two parts. Each of the above research aims was addressed within an initial study from which new equations for prediction of VO_2 peak were generated. Following on from this work, a second study was conducted in order to cross validate these new equations with a different sample of children. Methods & results for part (ii) are reported in sections 4.2.2 and 4.3.2.

4.2 METHOD

4.2.1 Part (i): Reliability study & validation of the 20m shuttle run test

(a) Subjects

Ethical approval for the research investigation was granted by Lothian Health Board, Paediatric/Reproductive Medicine Ethics of Medical Research Sub-committee (27/12/91). Lothian Regional Council, Department of Education Research Evaluation Committee was then provided with full details of the research proposal and formal permission obtained to approach named schools in Lothian Region for recruitment of the subject sample (2/9/92). A sample of 40 children was selected from the second year group of a state comprehensive school in West Edinburgh (School population, 1227 pupils). This number was comprised of 2 class group of 18 and 22 pupils respectively. Of these, 33 (15 boys and 18 girls) agreed to take part. Of the non participants, 1 boy refused consent on medical grounds, the others gave no reason. All children were aged between 13 and 14 years.

(b) General Procedures

A repeated measures, same subjects design was used to assess the reliability of the shuttle run test, the VO_2 Peak test and anthropometric measures. Each subject performed 3 treadmill tests, 3 shuttle run tests and had 3 sets of anthropometric measures recorded. Anthropometric measures and VO_2 peak tests were conducted at the Human Performance Laboratory, Queen Margaret College, Edinburgh. Shuttle run tests were conducted in the school gymnasium. Tests were administered in a randomised order and each test performed on separate occasions.

Due to practicalities, the day and time of each test could not be matched between subjects or between test days. Individuals completed all 6 maximal tests within a 5 - 10 week period. This long test period made allowance for restrictions of the school timetable and aided participation in those cases where tolerance for repeated maximal exercise was limited. The drawback of extending tests over such a period was the greater risk that children's fitness levels might change significantly over that time and thus interfere with the reliability analysis. At the end of each test session, subjects were questioned regarding their recent activity levels and in particular asked to indicate whether there had been any change to their normal pattern of activity. The reported habitual patterns of exercise of the children (including those whose tests spanned the full 10 week period) remained relatively unchanged and testers were confident that individual fitness levels were stable over the test period.

A preliminary meeting was set up with the children during the school PE class. All children and parents were then supplied with a letter of introduction, a consent form and an information booklet detailing each of the test procedures (See Appendix I). In addition to obtaining consent from the head teachers, parents and children, a standard letter was sent to all GPs informing them of the study and of those children from their practice who had been invited to take part. They were requested to advise the researcher if any child, for any reason, medical, social or otherwise, should not take part in the study. Parents were also informed that should they wish to consult a knowledgeable person regarding the maximal testing, Dr John Irving, Consultant Cardiologist, St. John's Hospital, Howden was willing to act as an independent advisor. Transport to and from the laboratory was arranged according to subject requirements with children attending the treadmill test sessions in groups of two or three. Children living close to the laboratory generally walked or cycled to test sessions. Those living further away, or attending sessions during PE when time was restricted, were transported by car or minibus.

Table 4.1: Test Order & Equipment: PHASE ONE

WEEK	TEST	EQUIPMENT	MANUFACTURERS
Part (i) Reliability study and validition of the 20m shuttle test			
1 - 10 s u m m e r	Height Weight Skinfold Thicknesses (3 tests per subject) VO_2 Peak (3 Tests per subject) Shuttle Test (3 Tests per subject)	Portable Stadiometer Scales Harpenden Skinfold Calipers Treadmill Heart rate Monitor On-line gas analysis system Shuttle Test Battery	Child Growth Foundation, London Seca, Germany Holtain, Germany Powerjog P30 Polar Electro, PE3000, Finland Covox Fitness Research System, Exeter National Coaching Foundation, Leeds
Part (ii): Cross validation study			
1- 6 a u t u m n	Height Weight Skinfold Thicknesses (1 test per subject) VO_2 Peak (1 Test per subject) Shuttle Test (2 per subject)	Portable Stadiometer Scales Harpenden Skinfold Calipers Treadmill Heart rate Monitor On-line gas analysis system Shuttle test battery	Child Growth Foundation, London Seca, Germany Holtain, Germany Powerjog P30 Polar Electro, PE3000, Finland Covox Fitness Research System, Exeter National Coaching Foundation, Leeds

(c) Anthropometric Measures

The anthropometric measures were carried out at the Human Performance Laboratory prior to the maximal exercise tests. Children wore light clothing (PE kit) and had training shoes removed. In general, measurements were recorded in the order, height, then weight, followed by skinfold thicknesses. To protect subject privacy, skinfold thickness measures were taken in a screened room adjoining the main laboratory. Prior to the study the tester was carefully trained in the techniques of antropometric measurement. Several researchers, familiar with and expert, in the techniques of skinfold thickness measurement in adults (Dr S.Kindlen, Dept of Nursing Studies, Queen Margaret College), and in children (Dr J.A. Payne, Dept of Child Life and Health, University of Edinburgh and Dr C. Ruxton, Dept of Dietetics, Queen Margaret College) were consulted. Using a small sample of children (n=4) and young adults (n=6) skinfold thickness measurements were recorded at each of the four body sites (triceps, biceps, subscapular, suprailiac) by both the tester and one of the trained advisors. Mean percentage difference between the two observers was small (3.5% for straight skinfold measurements, 2.6% when converted to a body fat percentage)

Height was measured using a portable stadiometer (Child Growth Foundation, London) according to the methodology of Lohman and colleagues (1991). Subjects stood erect, looking directly ahead with arms relaxed by their sides. Light upwards pressure was applied under the jaw and occiput with two hands to provide maximum extension of the spine. The child was asked to breath in and then out and to relax the shoulders, without lifting the heels from the ground The horizontal caliper was then lowered gently until it made contact with the highest point of the head and height recorded to the nearest 0.1 cm.

Weight was measured using standard portable weighing scales (Seca, Germany) to the nearest 0.5 kg. The scales were tested against calibrated beam balance scales using a relevant range of known weights (correlation between the two measurement systems prior to commencement of the testing programme was 0.99). The same procedure was used to check the accuracy of the scales at regular intervals throughout the study period.

Skinfold thickness measures were recorded using Harpenden skinfold calipers marked in divisions of 2mm. Measures were taken at four body sites (biceps, triceps, subscapular and suprailiac) according to the techniques of Lohman and colleagues (1991). Measurements were recorded from the right hand side of the body with the subject standing erect and with arms hanging relaxed at their sides. Using the thumb and finger of the left hand, the tester elevated a double fold of skin and subcutaneous adipose tissue about 1cm proximal to the site at which the skinfold was to be measured. The fold was raised perpendicular to the surface of the body and kept elevated until the measurement was completed. To ensure that only skin and adipose tissue were elevated, the skinfold was rolled lightly to remove any underlying muscle tissue. The measurement was made where the side of the skinfold was approximately parallel, midway between the general surface of the body near the site and the crest of the skinfold. In some cases where children were extremely overweight it was often difficult to secure a sufficient fold of skin to give a parallel sided skinfold. In these cases, two hands were used to elevate the skinfold. It is well documented that the source of error may be greater in obese subjects and to compensate for this a further measure was recorded (4 as opposed to the standard 3 readings). In all cases the measurement was made about 4 seconds after the pressure of the caliper jaws was released. It is recognized that if the caliper exerts force longer than 4 seconds, a smaller measurement will be obtained because fluid will be forced out of the tissues (Lohman et al, 1991).

All 4 skinfold thickness sites were located according to the techniques described by Lohman and colleagues (1991). The triceps skinfold was measured on the midline of the posterior aspect of the arm, over the triceps muscle, at a point midway between the lateral projection of the acromion process of the scapula and the inferior margin of the olecranon process of the ulna. The level of measurement was determined by measuring the distance between these two points using a tape measure and with the elbow flexed at 90 degrees. The mid point was marked on the lateral side of the arm using a felt tip pen. With the palm was directed anteriorly, the triceps skinfold was picked up in the midline posteriorly approximately 1 cm proximal to the marked level. The calipers were applied to the skinfold at the marked level.

The biceps skinfold was measured on the anterior aspect of the arm, over the belly of the biceps muscle. With the subject standing erect, upper arm relaxed and the palm directed anteriorly, a vertical fold was raised about 1 cm superior to the line marked for the triceps measure and the calipers applied at the marked level.

The subscapular skinfold was picked up on a diagonal, inclined infero-laterally approximately 45 degrees to the horizontal plane in the natural cleavage lines of the skin. The site was just inferior to the inferior angle of the scapula.

The suprailiac skinfold was located in the mid-axillary line immediately superior to the iliac crest. An oblique skinfold, aligned 45 degrees inferio-medially to the horizontal, was grasped following the natural clevage lines of the skin and the calipers applied 1cm from the fingers.

At all sites, three separate readings were taken to the nearest 0.1cm and the average recorded. Skinfold thickness measurement were recorded on three separate test days by the same trained observer.

(d) Treadmill test of Peak Oxygen Uptake (VO_2 Peak)

Safety Procedures

Maximal exercise testing is both physically and psychologically demanding, placing the individual under significant physiological stress. Due to this and in particular with view of the young age of the subjects, important safety procedures were introduced at the start of testing programme. Each child, their parent/guardian and their GP were supplied with full details of the test procedures. GP's were informed of the child's intention to participate (after parental consent was given) and requested to notify the tester should there be any medical contraindications to them undertaking a maximal exercise test. If doctors highlighted any areas of special concern parents were contacted again and the decision for the child to participate carefully reviewed. Two such cases arose. One child was subsequently withdrawn from the study, the other allowed to proceed after careful discussion with the parents and doctors concerned.

During the actual exercise tests, the following guidelines were adhered to:

- The temperature of the testing laboratory was maintained within 18 - 20 °C.
- All children were given a warm up (minimum 5 mins) prior to starting the test
- All children were given a warm down (gentle walking) after testing and heart rate monitored throughout the recovery period.
- No child was allowed to leave the laboratory until the tester was fully satisfied that they had recovered from the exercise bout, ie. heart rate was returned to near resting levels, subject showing no signs of physical distress, eg paleness, breathlessness, unsteady gait.
- Two adults were present in the laboratory during testing.

Treadmill VO_2 Peak Test Procedures

Children attended the treadmill test sessions in groups of 2/3. These groups tended to be same sex groups on the children's request. Each of the children were provided with an instructional leaflet prior to attendance at the laboratory tests. This was to confirm and remind them of the agreed time and transport arrangements, to provide them with a contact number should any problems arise and to ensure that they were appropriately prepared for the test i.e. no food consumed at least 2 hrs beforehand, PE kit essential. (See Appendix I)

The tests were carried out using a continuous incremental test protocol on a motorised treadmill (Powerjog P30). Oxygen uptake was measured directly every 30 seconds using an online gas analysis system (Covox Fitness Research System) incorporating an infra-red carbon dioxide analyser and a paramagnetic oxygen analyser (Servomex). Before each test the analysis system was calibrated using gases of known and guaranteed composition. Volume was assessed by a Rudolph pneumatotachometer (Hans Rudolph) which was calibrated prior to each test using a large (3 litre) Hans Rudolph calibration syringe.

The test protocol, selected following a pilot investigation of 3 different treadmill protocols (Appendix II), was similar to that used in previous studies of VO_2 Peak in children (Armstrong et al, 1990; Riddoch et al, 1990). Subjects were first allowed to become fully habituated with treadmill walking and running and then given a standard 5 minute warm up at 7/8 $km.h^{-1}$, depending on subject comfort. The familiarisation period varied markedly between subjects (5 - 20 minutes). Those children with highly developed running technique or with previous experience of treadmills appeared to accommodate quicker. Children were only allowed to proceed to the next stage once they could demonstrate a confident and relaxed running action on the treadmill. This was characterized by looking forward and straight ahead (not at feet), not having to use the side rails for support, and maintaining balance and regular cadence through various changes of speed and gradient.

Warm up was followed by 5 minutes rest after which the test commenced with a starting workload set at a velocity of 7/8 $Km.h^{-1}$ on a level treadmill. After 2 minutes the velocity was increased to 9/10 Km/h^{-1}. Thereafter a constant velocity was maintained and the gradient increased by 2% every 2 minutes until exhaustion. The test was terminated when the subject, despite strong verbal encouragement indicated that s/he could no longer maintain the pace. Polar Electro heart rate monitors (which were hard wired to prevent electromagnetic interference) were used to monitor heart rate throughout the test. To ascertain whether VO_2 Peak had been attained, at least 2 of the following criteria had to be fulfilled;

Criteria for establishing VO_2 Peak

- Peak recorded heart rate greater than 95% age predicted maximum (220 - age)
- Respiratory quotient greater than unity
- Subjective signs of fatigue, i.e. inability to keep pace with the ergometer, excessive sweating, facial flushing and unsteady gait.

Following completion of the test, all subjects were given a standard warm down which entailed gentle walking (approx. 3 $Km.h^{-1}$) until heart rate returned to less than 100 $beats.min^{-1}$.

Fig. 4.1 Child undergoing the treadmill test for VO_2 peak

(e) The 20m Shuttle run test

During this test, subjects are required to run 20 metre lengths in time to a pre-recorded "bleep" played on an audio cassette player. A commercially available tape was used (National Coaching Foundation, 1988) with initial velocity set at 8.5 $Km.h^{-1}$ and increasing by 0.5 $Km.h^{-1}$ every minute. The speed of the tape player was checked prior to each test and the same tape was used throughout. The procedures for the shuttle run test were piloted on several groups of undergraduate students prior to use with adolescent groups.

All tests were carried out indoors, either in the school gymnasium (synthetic flooring) or in the school dance hall (sprung wooden flooring), depending on availability. Prior to each test a 20 metre length was measured out using a long tape measure and clearly marked using corner cones and coloured tape. On arriving at the test session, children were sorted into test groups. Six to ten subjects were tested at any one time, allowing a minimum of 1m distance between individuals on the test. By request from participants, all groups were single sex. Names were recorded, by group, on a specially designed record sheet (See Appendix III) and each child allocated with a test code number. For easy identification during the test, this number was displayed on the chest and back using adhesive labels. Heart rate activity was monitored throughout using Polar Electro sports testers (PE3000, Finland). These were fitted prior to the test by the tester or trained assistant and set to record heart rate every 5 seconds. Subjects were requested to indicate the precise start and end of the test by using the marker facilities on the monitors (this was a simple procedure which involved pressing a button on the watch face).

Following an initial warm up session involving light jogging and stretching exercises, children were given a few minutes rest during which full instructions of the test procedures were provided. In addition to the standard test instructions relayed on the tape, the test was explained in full by the tester and a brief demonstration provided. They were instructed that they must place at least one foot over the 20m line before turning. It was stressed that each shuttle must be completed in full and that failure to touch the line at all before turning would result in disqualification. Subjects were verbally encouraged to run for as long as they could and the test was terminated when they failed to complete two consecutive shuttles within the time allowed. On subsequent tests, children were informed of their previous scores and encouraged to improve upon it. Performance on the test was assessed both by maximal running speed attained and by counting the total number of 20m laps completed.

(f) Data Analysis

All data was stored on a personal computer (RD Computer Systems, Edinburgh) and analysed using a standard computer software package (initially SPSS PC+, later converted to SPSS for Windows). Descriptive statistics (mean, standard deviation, and range), were determined for males and females. Differences between the sexes were assessed using the standard student t-test and accepted as significant at the 0.05 level. Variance of all measures taken over the three test days was assessed by using the intraclass correlation coefficient of reliability. Pearsons product moment correlations between the shuttle run test (assessed by maximal running speed and by the number of laps completed), VO_2 Peak (expressed both in absolute terms, $l.min^{-1}$, and relative to body weight, $ml.Kg^{-1}\ min^{-1}$) and the anthropometric measures were examined for both males and females. Multivariate regression analysis was then used to generate a number of prediction models for estimating VO_2 peak. Variables included in the analysis were height, weight, sex, individual skinfold thicknesses, sum of the triceps and subscapular skinfolds and the logarithm of the skinfold thicknesses (as used for the estimation of body fat). The VO_2 peak measurement used in the development of the prediction models was the mean of each of the subject's accepted VO_2 Peak tests. This allowed for potential measurement error of the gas analysis sytems and was deemed to provide the most accurate reflection of actual VO_2 Peak across the sample group.

4.2.2 Part (ii) Cross-validation study

(a) Subjects

Subjects for the cross validation study were recruited from a second state comprehensive school, also located in Edinburgh (School population, 1034 pupils). From a total of 40 pupils invited to participate, 25 (62.5%) returned consent. One subject was later withdrawn on the advice of the child's GP leaving a final sample of 24 (12 males, 12 females). As before, all children were aged 13 to 14 years.

(b) General Procedures

All subjects performed one treadmill test of VO_2 Peak, two shuttle run tests and had one set of anthropometric measures recorded. Procedures and test protocols for the shuttle test, treadmill test and anthropometric measures were as described for Part (i), but the number of repeat tests was reduced to save time. The VO_2 Peak prediction equations under review required only the best score from 2 repeat shuttle tests and consequently only 2 tests were performed. Likewise, due to the greater reliability of the VO_2 Peak test as established in part (i), only 1 treadmill test was performed (provided definitional criteria were met). In those cases where children failed to fulfill the specified criteria for VO_2 Peak (n=2), a retest was performed. All shuttle run tests were conducted at the gymnasium at Queen Margaret College with children transported to and from the college by minibus.

(c) Data Analysis

Descriptive statistics for males and females were determined and mean scores compared against the previous sample using students t - tests. VO_2 Peak (predicted from shuttle run performance using the newly developed equations) was compared against treadmill determined VO_2 Peak measured in the laboratory. Mean square error of the new equations was compared against mean square error produced by previously published equations (Barnett et al, 1993; Riddoch et al, 1990; Leger et al, 1988).

4.3 RESULTS

4.3.1 Part (i): Reliability and Validity of the 20m shuttle run test

(a) Descriptive statistics and comparison across gender groups

Physical characteristics by gender are presented in Table 4.2 below. There was no significant difference between the gender groups in relation to age, height, or weight. Girls however had significantly greater skinfold thicknesses at each of the 4 body sites and for the sum of the triceps and subscapular skinfolds (Biceps, t=-2.43, df=31; Triceps, t=-3.71, df=31; Subscapular, t=-2.51, df=21; Suprailiac, t=-2.63, df=31; Sum of triceps and subscapular, t=-3.21, df=24, for all $p<0.05$).

Table 4.2 Subject characteristics

	Male n=15		Female n=18
Age (years)	13.7 (0.3)		13.7 (0.3)
Height (cm)	161.0 (6.8)		156.8 (6.1)
Weight (Kg)	46.9 (8.7)		50.3 (8.8)
Skinfold Thicknesses:-			
Biceps	5.4 (2.8)	***	8.3 (3.9)
Triceps	9.3 (3.1)	***	15.1 (5.4)
Subscapular	7.8 (2.6)	***	12.7 (7.7)
Suprailiac	9.0 (4.1)	***	13.8 (6.0)
Triceps + Subscap.	17.1 (5.5)	***	27.8 (12.8)

Values indicated are the mean (+/- sd)

*** indicates significant difference between groups, $p<0.05$

Table 4.3 lists descriptive statistics for the VO_2 Peak and shuttle run tests. In both tests boys had significantly higher scores than the female group (For absolute VO_2 peak, t=2.96, df=20; for VO_2 Peak expressed relative to body weight, t=-5.24, $p<0.01$; For shuttle run test (No. of laps), t=-6.72, df=31, $p<0.01$). There was no significant difference in the peak heart rate between the two gender groups or between the laboratory and field tests. Maximal heart rates (defined as >95% age predicted maximum, Wilmore & Costill, 1994) were attained by 31 children (94%) during both the treadmill and the shuttle tests.

Table 4.3 Peak Oxygen Uptake and Shuttle Run Performance by Gender

	Male n=15		Female n=18
Treadmill VO_2 Peak absolute measure ($l.min^{-1}$)	2.4 (0.4)	***	2.1 (0.2)
Treadmill VO_2 Peak relative to body weight ($ml.Kg^{-1}.min^{-1}$)	53.2 (5.3)	***	42.9 (5.8)
Peak Shuttle Run (No. of laps)	68.0 (13.9)	***	41.8 (8.2)
Peak Shuttle Run (Maximal shuttle speed, $km.h^{-1)}$	12.0 (0.7)	***	10.8 (0.5)
Peak Heart Rate - T'mill test ($b.min^{-1}$)	200.0 (10.0)		203.7 (6.4)
Peak Heart Rate - Shuttle test ($b.min^{-1}$)	203.3 (8.8)		201.0 (6.7)

Values indicated are the mean (+/- sd)
*** indicates significant difference between groups, $p<0.05$

(b) Reliability Analysis

Anthropometric measures showed strong reliability. Height, weight, and all four skinfold thickness measures had an intraclass correlation coefficient greater than 0.94 (Table 4.4). Measures for the shuttle test and the VO_2 Peak test were less stable with intraclass correlation coefficients of 0.79 and 0.89 respectively. Reliability of the treadmill test of VO_2 Peak was examined in two ways. Firstly using **all** treadmill tests results and secondly using **only** those tests which fulfilled the definitional criteria for attainment of VO_2 Peak (RQ > 1.0, HR > 95% HRmax, subjective signs of fatigue). A total of 20 separate observations were discarded by this screening procedure. When all measured values of VO_2 Peak were included in the analysis, both those performances which met the specified criteria and those which failed, the observed intraclass correlation coefficient of reliability was only 0.75. After screening out those performances which could not be regarded as "maximal", reliability was considerably improved (intraclass correlation coeffiecent, R=0.89). Similar screening measures to identify maximal performances during the shuttle test could not be applied as equivalent physiological criterion measures were not available.

Table 4.4 Intraclass Correlation Coefficient of Reliability for each of the variables recorded over three separate test days (N=33).

Variable	Intraclass Correlation Coefficient
Height	0.99
Weight	0.99
Biceps	0.96
Triceps	0.97
Subscapular	0.97
Suprailiac	0.94
Shuttle Run (No of laps)	0.79
VO_2 Peak ($ml.kg^{-1}\ min^{-1}$) :- screened[5] values only	0.89
VO_2 Peak ($ml.kg^{-1}\ min^{-1}$) :- all values	0.75
Peak Heart Rate - VO_2 Peak test	0.71
Peak Heart Rate - Shuttle run test	0.69

Peak heart rate showed high variance both on the shuttle run tests (r=0.69) and the treadmill tests (r=0.71). It was noted that variance of an individual's peak heart rate did not show corresponding variance in performance scores. Highest heart rates did not always indicate an individual's best performance and maximal heart rates were frequently recorded during both peak and poorer performances. During better performances, peak heart rates were simply maintained for longer.

[5] "Screened" refers to analysis performed using data from those tests where individuals fulfilled the specified criteria for VO_2 Peak - all tests where definitional criteria were not achieved were omitted from the analysis.

Although variance between test days was indicated for both the shuttle and the treadmill tests (R=0.79 and R=0.89 respectively), repeated measures analysis of variance showed no significant difference between the means for any of the three test days (Table 4.5). Whilst not significant, boys mean performance on the treadmill test of VO_2 Peak appeared to be much poorer on the third test (55 $ml.Kg^{-1}.min^{-1}$ compared with 62 and 61 $ml.Kg^{-1}.min^{-1}$ on the previous two tests). In contrast to this, mean shuttle run performance for the boys was highest on the final test (57 laps attained in the third assessment compared with 51 and 52 laps in the earlier tests). Girls appeared to be extremely consistent on all tests.

Table 4.5 Performance Means (+/- sd) by gender and test number.

	Sex	Test 1	Test 2	Test 3
Shuttle Run	M	51.30 (5.5)	52.45 (6.6)	57.15 (18.8)
(No. of Laps)	F	39.61 (8.6)	39.61 (8.4)	35.13 (8.8)
VO_2 Peak	M	62.07 (14.0)	61.93 (15.4)	55.00 (5.4)
($ml.kg^{-1}$ min^{-1})	F	43.70 (6.9)	42.35 (5.8)	42.08 (6.4)
Height (cm)	M	160.93 (6.8)	161.07 (6.9)	161.23 (7.1)
	F	156.83 (6.0)	156.67 (6.1)	157.25 (6.2)
Weight (Kg)	M	46.57 (8.7)	47.13 (8.7)	47.00 (9.5)
	F	50.25 (8.8)	50.42 (8.9)	50.38 (9.0)
Biceps Skinfold	M	5.49 (2.8)	5.61 (3.5)	5.06 (2.4)
(mm)	F	8.41 (4.1)	8.35 (3.8)	8.34 (4.2)
Triceps Skinfold	M	9.23 (3.3)	9.25 (2.8)	9.38 (3.4)
(mm)	F	14.71 (5.2)	15.48 (5.4)	15.41 (5.9)
Subscapularis	M	7.98 (2.7)	7.79 (2.6)	7.68 (2.5)
(mm)	F	13.17 (8.1)	12.37 (7.4)	12.47 (8.4)
Suprailiac	M	9.19 (4.1)	9.09 (4.7)	8.92 (3.8)
(mm)	F	13.73 (5.5)	13.42 (6.5)	14.13 (6.9)

(c) Correlation and regression analysis

Correlations between VO_2 Peak (expressed both as an absolute measure, $l.min^{-1}$, and relative to body weight, $ml.kg.^{-1}min^{-1}$) and the selected variables were determined for both sexes (Tables 4.6 and 4.7). For the boys, absolute VO_2 Peak correlated significantly with the triceps skinfold thickness ($r=0.56$, $n=15$, $p<0.05$) and with the logarithm of the sum of the triceps and subscapular skinfolds ($r=0.56$, $n=15$, $p<0.05$). In girls, absolute VO_2 Peak correlated weakly with weight ($r=-0.50$, $p<0,05$) but not with any of the other variables recorded. When expressed relative to body weight, VO_2 Peak, showed strong correlations with the skinfold thickness measures and shuttle run performance, particularly in the female group

Table 4.6 Correlation Matrix (Males)

	Ab VO_2Pk	Rel VO_2Pk	No. of Laps	Max Shuttle Speed	Hgt	Wgt	Bicep	Tricep	Subsc	Suprail	Sum2	Sum4	(L)sum2
A- VO2 Pk	.	.	.	.	.	.	.	.	.	.	.	.	.
R-VO2 Pk	-0.15	.	.	.	.	.	.	.	.	.	.	.	.
Shuttle laps	-0.42	0.74*	.	.	.	.	.	.	.	.	.	.	.
Maxspeed	-0.38	0.78*	0.98*	.	.	.	.	.	.	.	.	.	.
Hgt	0.37	-0.40	-0.30	-0.29	.	.	.	.	.	.	.	.	.
Wgt	0.18	-0.48	-0.11	-0.13	0.88*	.	.	.	.	.	.	.	.
Biceps	0.34	-0.51*	-0.19	-0.31	0.33	0.30	.	.	.	.	.	.	.
Triceps	0.56*	-0.57*	-0.40	-0.47	0.40	0.57*	0.89*	.	.	.	.	.	.
Subscap	0.42	-0.58*	-0.30	-0.36	0.67*	0.73*	0.85*	0.90*	.	.	.	.	.
Suprail	0.34	-0.50	-0.25	-0.35	0.61*	0.61*	0.84*	0.86*	0.88*	.	.	.	.
Sum 2	0.51	-0.59*	-0.36	-0.43	0.54*	0.66*	0.89*	0.98*	0.97*	0.89*	.	.	.
Sum 4	0.43	-0.56*	-0.30	-0.39	0.53*	0.59*	0.93*	0.96*	0.95*	0.95*	0.98*	.	.
(L)sum2[$]	0.56*	-0.57*	-0.41	-0.46	0.70*	0.51	0.82*	0.97*	0.95*	0.84*	0.98*	0.94*	.
(L)sum4[$$]	0.52	-0.54*	-0.36	-0.42	0.65*	0.50	0.98*	0.96*	0.95*	0.92*	0.98*	0.98*	0.97*

[$] logarithmic function of the sum of the triceps and subscapular skinfold
[$$] logarithmic function of the sum of all four skinfold measures
* indicates significant correlation, $p<0.05$.

Table 4.7 Correlation Matrix (Females)

	Ab VO_2Pk	Rel VO_2Pk	No. of Laps	Max Shuttle Speed	Hgt	Wgt	Bicep	Tricep	Subsc	Suprail	Sum2	Sum4	(L)sum2
A-VO2 Pk	.	.	.	.	.	.	.	.	.	.	.	.	.
R-VO2 Pk	0.06	.	.	.	.	.	.	.	.	.	.	.	.
Shuttle laps	-0.01	0.80*	.	.	.	.	.	.	.	.	.	.	.
Max speed	0.09	0.79*	0.98*	.	.	.	.	.	.	.	.	.	.
Hgt	0.43	-0.25	-0.22	-0.24	.	.	.	.	.	.	.	.	.
Wgt	0.50*	-0.79*	-0.47	-0.42	0.44	.	.	.	.	.	.	.	.
Biceps	0.07	-0.71*	-0.58*	-0.48	-0.06	0.78*	.	.	.	.	.	.	.
Triceps	0.21	-0.76*	-0.49*	-0.47	-0.02	0.80*	0.86*	.	.	.	.	.	.
Subscap	0.18	-0.67*	-0.57*	-0.48*	-0.17	0.73*	0.90*	0.90*	.	.	.	.	.
Suprail	0.37	-0.58	-0.48*	-0.38	-0.11	0.73*	0.78*	0.88*	0.94*	.	.	.	.
Sum 2	0.20	-0.72*	-0.55*	-0.46	-0.11	0.78*	0.91*	0.96*	0.98*	0.94*	.	.	.
Sum 4	0.23	-0.70*	-0.55*	-0.46	-0.11	0.79*	0.92*	0.95*	0.98*	0.95*	0.99*	.	.
(L)sum2[$]	0.22	-0.73*	-0.53*	-0.45	-0.12	0.76*	0.84*	0.98*	0.95*	0.93*	0.98*	0.97*	.
(L)sum4[$$]	0.26	-0.70*	-0.53*	-0.44	-0.12	0.77*	0.86*	0.97*	0.96*	0.96*	0.99*	0.99*	0.99*

[$] logarithmic function of the sum of the triceps and subscapular skinfold
[$$] logarithmic function of the sum of all four skinfold measures
* indicates significant correlation, $p<0.05$.

In both sex groups, the strength of the correlation between VO_2 Peak and shuttle run performance was markedly improved by using the best shuttle run score after repeat tests. Correlations with relative VO_2 Peak using shuttle run score from the first test was 0.64 and 0.65 in males and females respectively, using the best score from two repeat tests gave 0.70 and 0.71, and using the best score after three repeat tests, 0.78 and 0.79. When data was restricted to a narrower age band (mean age (13.7 years) +/- 2 months) the correlation between shuttle run performance and relative VO_2 peak was improved in females but not in males (Maximal shuttle speed, Boys, r=0.75, Girls, r=0.87; Number of laps, Boys, n=0.70; Girls, n=0.90, n=9 and n=10 respectively).

Regression analysis was performed to determine the best predictors of VO_2 Peak ($ml.kg.^{-1}min^{-1}$) for the two sex groups. Table 4.8 and 4.9 provide a summary of the more pertinent findings. Throughout the analysis, the two measures of shuttle test performance, maximal shuttle speed and total number of shuttles completed, produced similar correlations and standard errors of the estimate. Only the results using shuttle test assessed by maximal running speed are reported here.

Table 4.8 Single Variable Predictor Models for estimating VO_2 Peak: Boys

Y Peak VO_2 ($ml.kg.^{-1}min.^{-1}$)	Predictor Variables	Coefficient(s) (Std.Error)	Constant (Std.Error)	R^2	SEE
VO_2 PEAK	Biceps	-0.96 (0.5)	58.34 (2.7)	0.23	4.74
VO_2 PEAK	Triceps	-0.97 (0.4)	62.12 (3.8)	0.32	4.53
VO_2 PEAK	Suscapular	-1.20 (0.5)	62.58 (3.9)	0.33	4.49
VO_2 PEAK	Suprailiac	-0.65 (0.3)	58.96 (3.1)	0.25	4.77
VO_2 PEAK	Sum 2	-0.56 (0.2)	62.80 (3.9)	0.34	4.46
VO_2 PEAK	Sum 4	-0.25 (0.1)	61.02 (3.4)	0.32	4.55
VO_2 PEAK	(L) Biceps	-6.31 (3.3)	63.22 (5.4)	0.22	4.86
VO_2 PEAK	(L) Triceps	-8.94 (4.0)	72.63 (8.7)	0.28	4.67
VO_2 PEAK	(L) Suscapular	-10.39 (4.0)	74.08 (8.2)	0.34	4.48
VO_2 PEAK	(L) Suprailiac	-6.23 (3.3)	66.33 (7.0)	0.23	4.87
VO_2 PEAK	(L) Sum 2	-23.36 (9.3)	81.51 (11.4)	0.32	4.53
VO_2 PEAK	(L) Sum 4	-8.85 (3.7)	83.19 (12.9)	0.30	4.62
VO_2 PEAK	Maxspeed(1)	5.01 (1.7)	-5.8 (19.7)	0.41	4.23
VO_2 PEAK	Maxspeed(2)	5.09 (1.4)	-7.57 (17.3)	0.49	3.93
VO_2 PEAK	Maxspeed(3)	5.95 (1.3)	-18.47 (16.1)	0.60	3.46

Maxspeed(1) = Max shuttle run speed after one test, $km.h^{-1}$.

Maxspeed(2) = Max shuttle run speed after two tests, $km.h^{-1}$.

Maxspeed(3) = Max shuttle run speed after three tests, $km.h^{-1}$.

Sum2 = Sum of two skinfolds (triceps and subscapular), mm

Sum4 = Sum of all four skinfolds (biceps, triceps, subscapular & suprailiac), mm

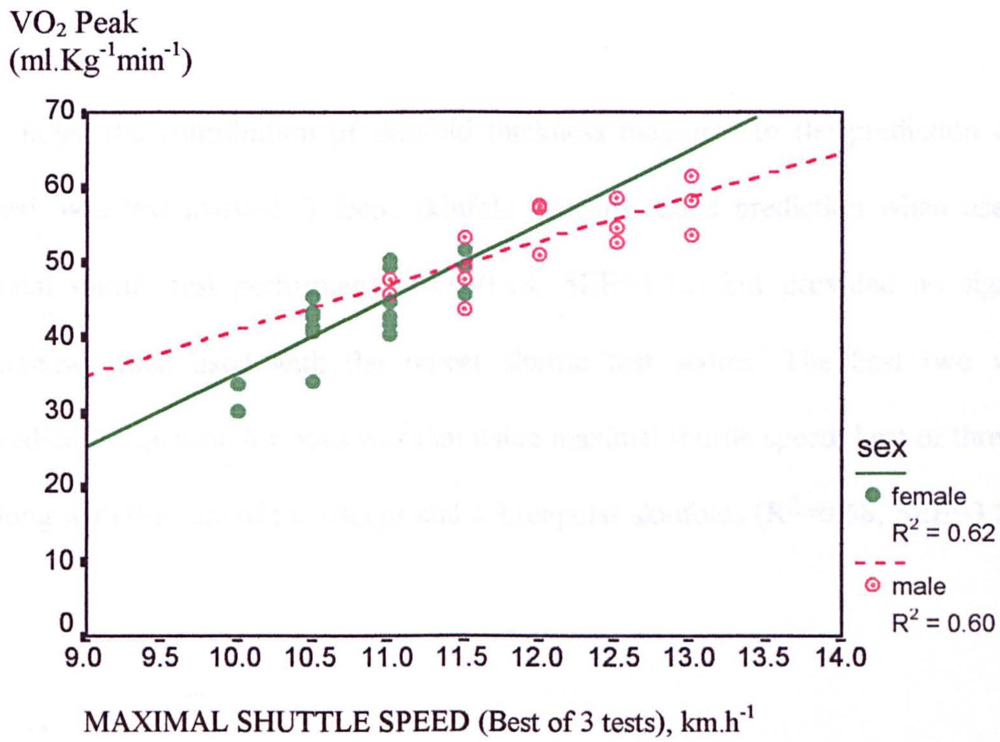
(L) = indicates logarithmic function

Table 4.9 Single variable predictor models for estimating VO_2 Peak: Girls

Y VO_2 Peak ($ml.kg.^{-1}min.^{-1}$)	Predictor Variables	Coefficient(s) (Std.Error)	Constant (Std.Error)	R^2	SEE
VO_2 PEAK	Biceps	-1.06 (0.3)	51.74 (2.4)	0.51	4.20
VO_2 PEAK	Triceps	-0.82 (0.2)	55.29 (2.8)	0.57	3.91
VO_2 PEAK	Suscapular	-0.51 (0.1)	49.33 (2.1)	0.45	4.43
VO_2 PEAK	Suprailiac	-0.56 (0.2)	50.66 (2.9)	0.34	4.86
VO_2 PEAK	Sum 2	-0.33 (0.1)	52.08 (2.4)	0.52	4.13
VO_2 PEAK	Sum 4	-0.19 (0.1)	52.19 (2.5)	0.50	4.24
VO_2 PEAK	(L) Biceps	-11.22 (2.9)	65.86 (6.0)	0.48	4.30
VO_2 PEAK	(L) Triceps	-12.50 (2.9)	76.15 (7.6)	0.55	4.03
VO_2 PEAK	(L) Suscapular	-7.72 (2.2)	61.50 (5.4)	0.43	4.51
VO_2PEAK	(L) Suprailiac	-7.89 (3.0)	62.99 (7.8)	0.30	5.01
VO_2 PEAK	(L) Sum 2	-24.43 (5.8)	77.33 (8.2)	0.53	4.11
VO_2 PEAK	(L) Sum 4	-10.81 (2.8)	84.38 (10.6)	0.50	4.28
VO_2 PEAK	Maxspeed(1)	7.74 (2.3)	-39.58 (24.4)	0.42	4.57
VO_2 PEAK	Maxspeed(2)	8.89 (2.2)	-52.58 (23.9)	0.50	4.23
VO_2 PEAK	Maxspeed(3)	9.97 (1.9)	-64.48 (20.8)	0.62	3.66

The best single predictor of VO_2 Peak was shuttle run performance (maximal running speed, best score from three tests), (Boys, R^2=0.60, SEE=3.46; Girls, R^2=0.62, SEE=3.66). Without repeat tests, the predictive power of shuttle run performance was low. Maximal shuttle run speed from the initial test could account for just 42 % (SEE=4.57) and 41 % (SEE=4.42) of the variance in the girls and boys respectively. Skinfold thickness measures were much stronger predictors of VO_2 peak in girls than for boys. The triceps skinfold, in particular, showed strongest predictive power for females (R^2=0.57, SEE=3.91). With pooled data for males and females (n=33), the best single predictor was shuttle run performance, best of three tests (R^2=0.77, SEE=3.64). When tested for interaction and for sex effect no significant differences were identified, however a plot of maximal shuttle run speed against VO_2 Peak (ml.kg.$^{-1}$min.$^{-1}$) did indicate a potential difference between the regression slopes for the two sexes (Beta regression coefficient was 5.95 (+/- 1.3) for males and 9.97 (+/- 1.9) for females). Figure 4.2 shows a graph of the relationship between VO_2 peak and shuttle run performance in the two gender groups.

Fig 4.2 Relationship between VO_2 Peak and maximal shuttle run speed showing regression lines for males and females



Two variable predictor models were also generated (Summarised in Tables 4.10 and 4.11 overleaf). For both the male and the female groups predictive power was improved by the addition of skinfold thickness measures into the equation. In girls, the most significant increase in predictive power was achieved by the model incorporating maximal recorded speed after 3 tests and triceps skinfold thickness (R^2= 0.85, SEE=2.40). With the inclusion of the triceps measure, the influence of repeat tests was reduced. Even when the maximum speed from the first test was used, predictive power was high (R^2=0.79, SEE=2.83). Conversion of skinfold measures to their logarithmic function did not significantly alter the predictive power.

In boys, the contribution of skinfold thickness measures to the prediction of VO_2 Peak was less marked. Triceps skinfold measure aided prediction when used with initial shuttle test performance (R^2=0.58, SEE=3.72) but provided no significant increase when used with the repeat shuttle test scores. The best two variable prediction equation for boys was that using maximal shuttle speed, best of three tests, along with the sum of the triceps and subscapular skinfolds (R^2=0.68, SEE=3.23).

TABLE 4.10: Summary of the multiple regression analysis for VO_2 Peak, shuttle run performance and other selected variables: Boys.

Y VO_2 Peak ($ml.kg.^{-1}min.^{-1}$)	Predictor Variables	Coefficient(s) (Std.Error)	Constant (Std.Error)	R^2	SEE
VO_2 PEAK	Maxspeed(1)	4.09 (1.5)	26.18 (22.8)	0.58	3.73
	& (L) Sum2	-17.38 (8.0)			
VO_2 PEAK	Maxspeed(2)	3.83 (1.4)	29.61 (21.3)	0.58	3.71
	& (L) Sum2	-18.48 (7.9)			
VO_2 PEAK	Maxspeed(3)	5.01 (1.4)	6.43 (23.2)	0.66	3.32
	& (L) Sum2	-11.12 (7.7)			
VO_2 PEAK	Maxspeed(1)	4.10 (1.5)	12.30 (18.5)	0.60	3.62
	& Sum2	-0.43 (0.2)			
[6]VO_2 PEAK	Maxspeed(2)	4.15 (1.3)	10.28 (17.2)	0.64	3.46
	& Sum2	-0.39 (0.2)			
VO_2 PEAK	Maxspeed(3)	4.94 (1.4)	-1.16 (18.1)	0.68	3.23
	& Sum2	-0.30 (0.2)			

Maxspeed(1) = Max shuttle run speed after one test, $km.h^{-1}$.

Maxspeed(2) = Max shuttle run speed after two tests, $km.h^{-1}$.

Maxspeed(3) = Max shuttle run speed after three tests, $km.h^{-1}$.

Sum2 = Sum of two skinfolds (triceps and subscapular), mm.

[6] This equation was the one finally selected for the prediction of peak oxygen uptake (males only) in Phase 3. It showed strong predictive power and the measures required (two repeat shuttle run tests in conjunction with skinfold thickness measures) were practical in terms of their time, labour and cost demands. Refer to discussion for further details.

TABLE 4.11: Summary of the multiple regression analysis for VO_2 Peak, shuttle run performance and other selected variables: Girls.

Y VO_2 Peak ($ml.kg.^{-1}min.^{-1}$)	Predictor Variables	Coefficient(s) (Std.Error)	Constant (Std.Error)	R^2	SEE
VO_2 PEAK	Maxspeed(1) & (L) Triceps	6.03 (1.5) -10.55 (2.08)	6.68 (17.8)	0.79	3.73
VO_2 PEAK	Maxspeed(2) & (L) Triceps	6.62 (1.5) -9.71 (2.1)	-2.50 (19.1)	0.79	2.79
VO_2 PEAK	Maxspeed(3) & (L) Triceps	7.52 (1.4) -8.68 (1.8)	-15.09 (17.0)	0.85	2.38
VO_2 PEAK	Maxspeed(1) & Triceps	5.78 (1.5) -0.68 (0.1)	-8.39 (16.3)	0.79	2.83
[7] VO_2 PEAK	Maxspeed(2) & Triceps	6.30 (1.6) -0.63 (0.1)	-15.36 (17.8)	0.79	2.81
VO_2 PEAK	Maxspeed(3) & Triceps	7.26 (1.4) -0.56 (0.1)	-26.86 (15.8)	0.85	2.40

Maxspeed(1) = Max shuttle run speed after one test, $km.h^{-1}$.

Maxspeed(2) = Max shuttle run speed after two tests, $km.h^{-1}$.

Maxspeed(3) = Max shuttle run speed after three tests, $km.h^{-1}$.

(L) Triceps = Logarithmic function of triceps skinfold thickness.

[7] This equation was the one finally selected for the prediction of peak oxygen uptake (females only) in Phase 3. It showed strong predictive power and the measures required (two repeat shuttle run tests in conjunction with skinfold thickness measures) were practical in terms of their time, labour and cost demands. Refer to discussion for further details.

4.3.2 PHASE 1: Part (ii): Cross validation of the new equations

The new VO_2 Peak prediction equations generated in part (i) (and highlighted in tables 4.10 and 4.11), were evaluated further using a new sample of children (n=24). Subject characteristics of the validation sample are shown in Table 4.12 below.

Table 4.12: Subject Characteristics (Validation Sample)

	Male n=12		Female n=12
Age (years)	14.1 (0.5)		14.2 (0.3)
Height (cm)	163.6 (3.5)		160.3 (7.3)
Weight (Kg)	54.3 (5.6)		52.4 (6.4)
Skinfold Thicknesses:-			
Biceps	5.1 (2.3)	***	8.0 (3.1)
Triceps	10.3 (4.2)	***	17.3 (5.8)
Subscapular	8.3 (3.1)		10.1 (3.1)
Suprailiac	12.2 (8.0)		13.7 (4.9)
Triceps + Subscap.	18.5 (7.0)	***	27.4 (8.7)

*** Denotes significant difference between groups, $p<0.05$

Comparison between males and females yielded a similar pattern to that of the previous sample. There was no significant difference between males and females in relation to age, height, weight, or peak heart rate. Significant differences were identified for VO_2 peak (t=5.57, df=22, $p<0.05$), for shuttle run performance (No of laps, t=4.66, df=22; maximal shuttle speed, t=5.39, df=22, $p<0.05$), biceps skinfold (t=-2.63,df=22), triceps skinfold (t= -3.41,df=22) and for the sum of the triceps and subscapular skinfold (t=-2.77, df=22,p<0.05). Mean suprailiac skinfold for males was greater than for the previous sample (36% increase) and differences between the sexes on this measure were not significant.

Table 4.13 Peak Oxygen Uptake and Shuttle Run Performance by Gender

	Male n=12		Female n=12
VO_2 Peak relative to body weight ($ml.Kg^{-1} min^{-1}$)	53.3 (5.3)	***	41.0 (5.5)
Peak Shuttle Run (No. of laps)	68.2 (14.3)	***	40.5 (14.8)
Peak Shuttle Run (Maximal shuttle speed, $km.h^{-1}$)	12.0 (0.6)	***	10.6 (0.7)
Peak Heart Rate - T'mill test ($b.min^{-1}$)	202.7 (4.6)		198.0 (8.1)

*** Denotes significant difference between groups, p<0.05

Examination of the differences between the two data sets (pupils from part i and pupils from part ii), showed children from the latter set to be significantly older by 5 months (boys, t=2.76, df=25, p<0.05; girls, t=4.18, df=28, p<0.05). Boys from the latter sample were also heavier (t=2.52, df=25,p<0.05). No significant differences were identified between the groups for any of the other variables.

Three sets of equations for predicting VO_2 peak were examined:

1) *Equations developed in previous section (Refer to tables 4.10 & 4.11, p.111)*

- **For males**: Y (VO_2 Peak, $ml.Kg^{-1}min^{-1}$) = 4.15 (Maximal shuttle speed, best of 2 tests, $km.h^{-1}$) - 0.39 (Sum of triceps & subscapular, mm) + 10.28
- **For females**: Y (VO_2 Peak, $ml.Kg^{-1}min^{-1}$) = 6.3 (Maximal shuttle speed,best of 2 tests, $km.h^{-1}$) - 0.63 (Triceps, mm) -15.4

2) *Equations developed by Barnett et al (1993)*

- Y (VO_2 Peak, $ml.Kg^{-1}$ min^{-1}) = 28.3 - 2.1(sex) - 0.7 (Triceps skinfold, mm) + 2.6 (Maximal shuttle speed, $Km.h^{-1}$)

3) *Equations developed by Leger et al (1988)*

- Y (VO_2 Peak, $ml.Kg^{-1}$ min^{-1}) = 31.025 + 3.238 (Max.shuttle speed, 1 test, $Km.h^{-1}$) - 3.248 (age, years) + 0.1536 (age, years)(max. shuttle speed, $Km.h^{-1}$)

For each of the selected prediction equations, predicted values were compared with directly measured values. The root mean square error for each equation was; Equation 1 (4.35 $ml.Kg^{-1}$ min^{-1}), Equation 2 (4.11 $ml.Kg^{-1}min^{-1}$) and Equation 3 (4.70 $ml.Kg^{-1}$ min^{-1}). Root mean square error, expressed as a percentage of the sample mean, was 9.2, 8.7 and 10.7 respectively. Prediction error across the sample was examined by a plot of the Actual - Predicted difference for each of the 3 equations (See Figures 4.2, 4.3 & 4.4). Both Equations 2 and 3 showed a similar trend in prediction, a tendency to over predict the high performers and under predict the poor performers. Equation 1 show a more even pattern of prediction error across the performance spectrum.

Fig 4.3 Prediction error: Leger et al (1988)

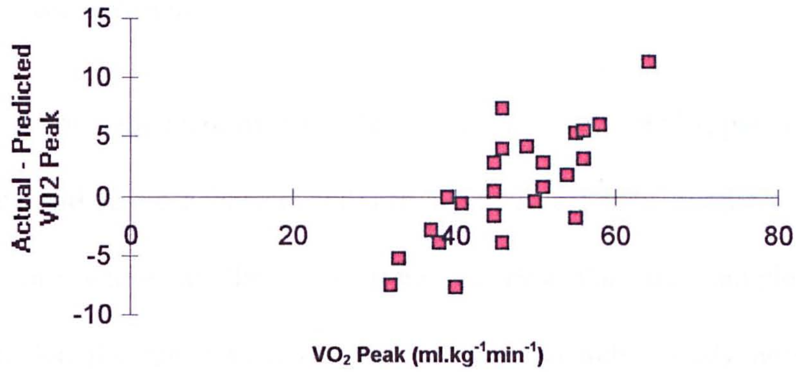


Fig 4.4 Prediction error: Barnett et al (1993)

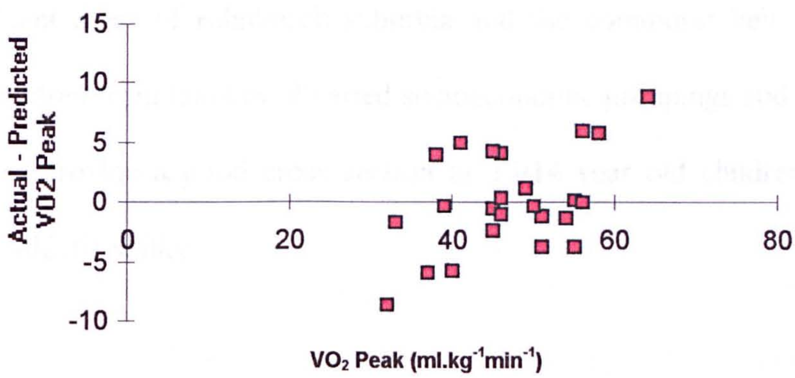
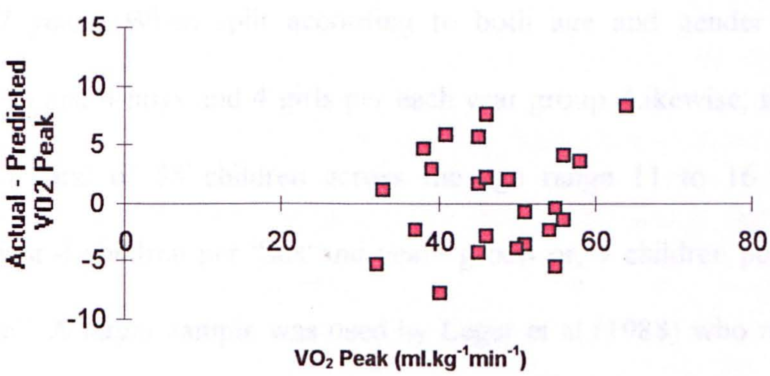


Fig 4.5 Prediction error: McVeigh et al



4.4 DISCUSSION

4.4.1 Sample Recruitment

The sample size for both sections was relatively small (part i, n=33; part ii, n=24). A careful balance had to be achieved between gaining sufficient numbers to warrant statistical validity whilst at the same time ensuring that the sample size was manageable within the given time restrictions. The reliability study necessitated a considerable number of repeat tests with all participants ideally completing 6 maximal tests. The two selected schools were non selective, non denominational, and had wide catchment areas extending across several of Edinburgh's poorer housing estates to the more affluent areas of Edinburgh suburbia and the commuter belt. They thus represented children from families of varied socioeconomic groupings and the sample was deemed to provide a good cross section of 13/14 year old children of mixed academic and athletic ability.

Compared to other studies, the sample group contained a substantially larger number of children of similar chronological age allowing more careful analysis of within age group differences. Barnett et al (1993) used a sample of 55 children between the ages of 12 and 17 years. When split according to both age and gender groups this approximates to just 4 boys and 4 girls per each year group. Likewise, Riddoch et al (1992) used a total of 55 children across the age range 11 to 16 years, again averaging to just 4 children per "sex and year" group or, 9 children per "sex and 2 year age range". A larger sample was used by Leger et al (1988) who recruited 188 children from 8 to 19 years. Their study however did not examine the use of anthropometric measures for assisting prediction of VO_2 peak from shuttle run performance.

4.4.2: Reliability study

Reliability of all anthropometric measures (height and weight along with biceps triceps, subscapular and suprailiac skinfold thicknesses) across each of the test days was high. Height and weight measures showed strongest reliability (R=0.99 for both) but all skinfold thickness measures also yielded intraclass correlation coeffiecents greater than 0.93. Undoubtedly this was promoted by the measures on each test day being recorded by one tester only. Previous investigations have indicated large inter-observer differences for skinfold thickness measures (Lohman et al, 1991; Johnson & Mack, 1985) particularly with inexperienced observers (Walker & Kindlen, 1988). The researcher recording the skinfold thickness measures for the current study trained with several experienced observers prior to commencement of the study.

Part of the aims for this reliability study was to determine assessment procedures for Phase 3 of the investigation. In view of the high reliability shown, it was noted that repeat testing of anthropometric measures on separate days may be unnecessary and that a single test day would suffice. This supports the general practice of recording repeat readings of anthropometric measures but recording them on **one** day only as demonstrated in many other studies (Armstrong et al, 1990, 1991; Northern Ireland Fitness Survey, 1989; Kemper et al, 1989). It was also proposed that for Phase 3, skinfold thickness measures would be recorded from 2 body sites only (the triceps and subscapular sites). The recording of just the triceps and subscapular skinfold thickness measures would present more economical use of assessment time whilst still being in accordance with techniques recommended, and used, by other researchers (Janz et al, 1993; Armstrong et al, 1991, 1990; Slaughter et al, 1988).

Reliability of both the treadmill VO_2 peak and shuttle run performance were shown to be less stable than the anthropometric measures. Peak heart rates recorded during these tests were also extremely variable. In Freedson and Goodman's review (1993) of the measurement of VO_2 peak, a range of reliability correlation coefficients from 0.53 to 0.99 was reported. Their study included studies of both cycle and treadmill determined VO_2 peak values. Figures from the current study lie at high end of this range (R=0.89, n=33, when screened for non maximal effort). Reliability of the treadmill VO_2 peak test was markedly improved by using definitional criteria to identify those tests when the desired exhaustive state was not attained (14% of the treadmill tests performed). Use of strict criterion for defining the attainment of VO_2 peak is clearly important for maintaining the level of reliability, since when all VO_2 peak scores were used, including those where criterion standards were not achieved, reliability was considerably lower (r=0.75, n=33).

Very little is reported in the research literature on the reliability of the shuttle run test, particularly in adolescent populations. One study, Leger et al (1988) reported reasonably high standards of reliability for the shuttle run test across a wide age range of children (r=0.89, 139 boys and girls, 6 - 16 years). Reliability of the shuttle run test as identified in this study was lower (R=0.79 over 3 test days, n=33) and indicates some variability in performance across days. Some children appeared to be extremely consistent across the three test days (within 1 or 2 laps), others showed marked variability (differing by up to 2 levels between test days). This lower reliability could, of course, be attributed to methodological error, such as inconsistencies in test administration procedures or to variance in the environmental conditions. However, the same tester was used for all repeat tests and throughout the tester endeavoured to maintain a consistent protocol. There was no significant effect according to the day of testing, and no relationship between subject maximal performance and test day was apparent. This suggests that variability in performance may be due to differences in motivation rather than to any learning effect or inconsistencies in test administration. Indeed, during testing, it was often obvious that some children had "bad days" when they appeared to try less hard. Some children freely offered reasons for their poorer performance e.g. "couldn't be bothered today", "growing pains", "too tired".

As the use of maximal tests for the assessment of "normal" populations (as opposed to "athletic" populations) becomes increasingly popular, the potentially wider differences in subject motivation must be accounted for. Rowland (1993) presented a detailed review of aerobic exercise testing protocols for children and highlighted a number of important requirements for maximal testing. Whilst he recommended that tests should not be too long "to avoid subject boredom" nor too short as to be overly intense and "intimidating to the unfit subject", the importance of subject motivation was not given the emphasis it perhaps deserves. The treadmill and shuttle run tests yielded intraclass correlation coefficients of 0.75 and 0.79 respectively, indicating a marked day to day variability in performance. Why some children were more erratic, in terms of their performance, than others is unclear, especially given the specially standardised test procedures. Whether this individual variability in day to day performance may be linked to psychological factors (motivation, attitudes to sports, self efficacy and so on) warrants further research.

For the present, it must not be assumed that motivation is similar for all individuals or that it is stable across time. The need to achieve maximal performance from the subjects is paramount to the success of the shuttle run test as a measure to predict VO_2 peak and therefore strategies and protocols must be adopted which endeavour to achieve this. It is acknowledged that motivating subjects to push themselves to exhaustion, especially if some typically regard themselves as "non athletic" and "non sporty" is a challenging directive. Given the infinite variety of personalities and abilities, it is virtually impossible to identify, or to prescribe, optimum conditions for every individual but researchers should consider specific techniques and strategies to encourage subjects to strive for a maximal performance.

During the direct measurement of VO_2 Peak in the laboratory, problems of identifying the peak from the non peak performance, are avoided by the use of strict physiological criteria to define whether a maximal performance has been achieved (BASS position statement, Hale et al, 1988) . This suggests that definitional criteria similar to those utilised for the VO_2 peak test could, and should be, employed within the shuttle run test protocol. Such techniques however are impractical for use in the field. Whilst the recording of heart rate during the shuttle test is possible, as demonstrated in this study, it was observed that heart rate could not be used in isolation as a discriminatory measure. Most subjects (94%) managed to attain maximal heart rates (>95% age predicted max) and these were attained during both better and poorer individual performances. If it was to be used as a criteria for indicating maximal performance, other physiological and subjective indicators would be required to support it. Measures such as lactate levels and respiratory quotient could be employed to supplement and validate the heart rate data. Unfortunately, the inclusion of such measures would inevitably undermine one of the shuttle tests greatest assets:- its simplicity. The recording of heart rate data involves the setting up and careful operation of electronic monitors, whilst the other measures would demand blood samples and expensive, sophisticated equipment. The requirement of blood samples would also have ethical and legal implications if the test was to continue to be used in the school setting.

One indicator of maximal performance which could be incorporated relatively easily into the shuttle run test is the Borg "Rating of Perceived Exertion" (RPE) scale (Borg, 1982, 1970). This is commonly a simple 15 point scale ranging from a rating of 6 (very, very, light), through 13 (somewhat hard), 15 (hard) and 19 (very, very hard), to 20 which denotes exhaustion Subjects are simply asked to indicate their subjective level of perceived exertion at specific points during the selected exercise/activity. High correlations between RPE and heart rate (r=0.8-0.9) have been reported (Borg, 1982). To make the scale easy to use within the lay population, a simple 10 point scale ranging from 1 (very, very weak/ light) to 10 (very, very strong/ almost max) was also devised (Borg, 1982). The use of this scale for field based maximal tests has not been addressed within the available research literature. Its potential as a simple, cheap and practical screening measure deserves investigation.

The alternative proposed by this study as a possible compensatory measure for the lack of physiological indicators for defining maximal performance is the use of repeat testing. Although repeat testing cannot guarantee maximal performance, it can account for some of the variance in individual performance across test days and can disclose any obvious inconsistent results between tests. The predictive power of the shuttle run test for estimating VO_2 peak was improved by 20% using maximal shuttle run performance from 3 repeat tests (R^2=0.6 for males and females) compared with shuttle run performance from just one test (R^2=0.4 for males and females).

Repeat testing would also be advantageous to epidemiological studies by minimising the number of children missed from any sweep survey due to absenteeism. Testers would be more likely to "catch up" on children who were absent from school during the first assessment. Some children clearly benefited from the repeat testing procedures. Having completed one test many children had a target to aim for and could push themselves beyond that mark. Others however appeared to push themselves on the first test and then getting "bored" with it failed to attain the same level on subsequent tests. Different strategies worked for different individuals. One obvious problem with the shuttle test was that when one individual was left at the end of the test, they often tended to drop out before reaching their potential maximum. Having "won the competition" there was little incentive to push themselves further.

Whilst it is inevitable that one individual is left at the end of the test, it was found beneficial to place subjects of similar ability together in the same test group. Boys in particular were inclined to compete with each other and as a result often appeared to push themselves harder when placed with "rivals". Repeat testing had the additional advantage of providing the final runner with a previous score to challenge if none of the other runners could offer sufficient competition.

Some children, especially girls, expressed concern if placed in a group where they felt they were the weakest and many especially did not want to "run with the boys". In several cases, girls did not even like to have the boys present in the gymnasium watching them. Girls also appeared to be less competitive with each other than the boys. Some tended to stick together as friends throughout the test and there was concern that certain individuals were inclined to drop out as a "team" rather than running as individuals. A future improvement for the test would be to consult with teachers for advice on which groups of children this "running chumming" would likely to be a problem. Active steps could then be taken to ensure that "best friends" were not placed in the same test group.

As a final observation in regard to the reliability of the shuttle run test, it should be noted that whilst shuttle run scores showed variability between different tests for individuals, no significant difference between the group mean for each of the three test days was identified. This implies that whilst the test has noted limitations as a measure of aerobic fitness in individuals and all test results must subsequently be viewed with a degree of caution, the test does appear to provide a reliable measure for the assessment of populations. This is an encouraging finding and supports the use of the shuttle run test for Phase 3 of this investigation and for future epidemiological studies.

4.4.3 The 20m shuttle run test as a predictor of VO_2 Peak in children

Review of the current research evidence identified a lack of consensus regarding the validity of the 20m shuttle run test as a predictor of VO_2 peak in children. In view of this it was necessary to reappraise the effectiveness of the measure within the selected 13 to 14 year old age group. Descriptive statistics for the sample group were examined prior to the correlation and regression analysis. Height, weight and skinfold thickness measures were in close agreement with reports from other studies and were typical for children of that age group (Suter & Hawes, 1993; Armstrong et al, 1990; Northern Ireland Fitness Survey, 1989; Tell & Vellar, 1988). As found in these studies, boys were leaner than the girls but of similar height and weight, reflecting the gender specific changes in lean to fat mass ratio that take place during puberty.

The correlation between VO_2 Peak and shuttle run performance was low when only one test was performed. The findings ($r= 0.60$ and 0.65 for males and females respectively) are in close agreement with those reported by van Mechelen and colleagues (1986), (Boys $r=0.68$, $n=41$, Girls, $r=0.69$, $n=41$) and occupies the middle ground between the low correlations reported by Armstrong et al, 1985 ($r=0.54$) and the higher correlations reported by Leger et al, 1988 ($r=71$). Low reliability of the shuttle test, as identified in part (i) may partly account for these weaker correlations. As demonstrated, a better estimate of maximal performance can be achieved through the use of repeat testing and this in turn can help to improve the prediction of VO_2 Peak from shuttle run performance. Armstrong and co-workers (1988) expressed reservations regarding the use of the shuttle test as a predictor of VO_2 Peak in view of its poor reliability and suggested that it's future application lay purely as an educational tool rather than as a scientific measure. Results from this study however imply that the shuttle run test can offer a reasonable estimate of VO_2 Peak provided at least two repeat tests are performed.

No significant difference was detected between the sexes or the fitness tests in relation to peak heart rates. Both boys and girls appeared to push themselves to a similar extent on both tests (despite individual variability across test days). Most subjects (94%) managed to attain maximal heart rates (>95% age predicted max) and these were attained during both better and poorer individual performances. This finding suggests that the contribution of anaerobic mechanisms during the final stages of the shuttle test may be important. The question then arises (supporting the concern expressed by Armstrong and colleagues (1988) regarding the noted limitations of the shuttle run test) as to whether the shuttle run test can be used as a measure of aerobic power. It is obviously not an absolute measure of VO_2 peak and other factors beyond the efficiency of oxygen transport/metabolism limit test performance. The energy requirements for turning at the end of each shuttle may rely on anaerobic metabolism. Perhaps the 'problem' of the shuttle test as an indicator of aerobic performance in children is that it is influenced by an individual's anaerobic capacity in a manner which is less apparent during the direct measurement of VO_2 Peak. Further investigation is required to determine the extent to which shuttle test performance may draw upon anaerobic as well as aerobic energy reserves.

Many combinations of anthropometric and shuttle run performance variables were used to generate prediction formulae for estimating VO_2 Peak. Higher common variance was obtained using pooled data for males and females. This is in agreement with previous studies and may be attributed to the wider range of VO_2 Peak values incorporated within the correlation analysis (Barnett et al, 1993, van Mechelen et al, 1986). Although no significant differences between the gender groups were identified, only guarded assumption can be made regarding the compatibility of the groups in view of the relatively small sample size. The plot of VO_2 Peak (ml.kg.$^{-1}$ min.$^{-1}$) against shuttle run performance (best of three tests) (See Fig. 4.2) showed distinct gender groups and divergent regression lines for the two sexes. Previous studies have been equivocal regarding the significance of the gender factor in VO_2 Peak prediction (Barnettt et al, 1993, Leger & Lambert, 1982; Leger et al, 1988). Until the effects of gender on the relationship between shuttle run performance and VO_2 Peak are rigorously assessed, separate analyses for the gender groups should be maintained. All subsequent analyses for this study maintained the gender division.

The multiple regression analysis indicated that the inclusion of skinfold thickness measures could significantly increase predictive power. The best indicator of VO_2 Peak in girls, was maximal shuttle run performance along with triceps thickness measure. This supports the findings of Barnett et al (1993) and highlights similarities between the Scottish and Chinese student groups. These similarities are perhaps all the more notable given the wide geographical, socio-economic and cultural differences that exist between the two groups. Since triceps skinfold thickness is a useful indicator of body fat in children (Slaughter et al, 1990), the inclusion of this measure in the regression equation may help to account for differences in running economy and running styles between fat and lean individuals. Skinfold thickness measures appeared to be less valid predictors of VO_2 Peak in boys, as evidenced by the lower correlations. The addition of the sum of the triceps and the subscapular skinfolds to the prediction equation did however significantly improve predictive power. For both sexes, the inclusion of skinfold measures (triceps or sum of triceps and subscapular) makes important contribution toward accurate prediction of VO_2 Peak ($ml.kg.^{-1}min.^{-1}$).

It is notable that the inclusion of skinfold measures may also reduce the requirement of repeat testing. In the case of the girls, predictive power was similar when triceps skinfold thickness was used in conjunction with either maximal shuttle speed from one test (R^2=0.79, SEE=2.83) or two tests (R^2=0.79, SEE=2.81). For those prediction equations where skinfold thickness is accounted for (Barnett et al, 1993, Riddoch et al, 1992), the use of only one shuttle run test may therefore be acceptable. If a measure of body composition is not considered, as is typical of the earlier prediction equations developed for children (Boreham et al, 1990; Leger et al, 1988), at least two repeat tests are strongly recommended[8].

[8] These findings regarding the validity and reliability of the 20m shuttle run test as a predictor of peak oxygen uptake in children have been summarised within a separate research paper. This paper was published in the refereed American journal, Pediatric Exercise Science, Feb 1995. A copy is provided in Appendix IV.

A cross validation study was conducted in order to examine how the new equations would perform against a different sample of children. Three prediction equations (that generated by Leger et al, 1988; Barnett et al, 1993 and that from the present study) were examined. The latter two equations were shown to have lowest root mean square error and the use of skinfold thickness measures in conjunction with shuttle run performance for the prediction of VO_2 peak was strongly supported. The inclusion of skinfold thickness measures can account for some of the variability between individuals and is a valuable addition to the prediction model.

The value of the new equations was in their capacity to predict across a wide range of subject abilities. Both the Barnett et al (1993) and the Leger et al (1988) equations appeared to be less accurate predictors of children at the extremes of the performance spectrum tending to over-predict those with low VO_2 peak and under predict those with high VO_2 peak. Only the equation developed in this study was able to demonstrate uniformity in prediction error across the sample. This reflects the greater number of children within the 13 to 14 year age range in this study and highlights the need to account for maturational differences within age groups. Whilst the equation developed by Barnett and colleagues (1993) is valuable in that as it covers a wide range of ages (12 to 17 years) and is readily applicable to children throughout the secondary school years, it seems unlikely however that one equation can adequately reflect differences within (as well as across) age groups. The findings from this study need to be supported by further research and work should be extended to cover children outwith the narrow 13/14 age group. The development of separate equations for each age or maturational group needs to be investigated.

In conclusion, a thorough review of the twenty metre shuttle run test as a predictive measure of VO_2 peak in 13 to 14 year old children has shown it to offer a reasonable estimate of peak oxygen uptake provided that repeat testing is conducted and that anthropometric measures are included in the prediction equation. It was found to be relatively easy to administer in the school setting, requiring a minimum of equipment, and utilising the schools' own PE facilities. Many children were found to be already familiar with the test and those that were unfamiliar with it found the procedures easy to follow. One of its most practical assets was that many children could be tested together and they could be tested indoors. Most school gyms follow a similar design format thus creating a relatively standard test environment for all children. On the basis of these findings, the 20 metre shuttle run test is accepted as a reliable and valid predictor of VO_2 peak in children, 13 to 14 years, and use of the test within Phase 3 of this investigation is supported.

CHAPTER FIVE

PHASE 2:

EVALUATION OF METHODS OF HEART RATE DATA ANALYSIS AS A MEASURE OF PHYSICAL ACTIVITY IN CHILDREN

5.1 INTRODUCTION

Continuous heart rate monitoring offers an objective physiological indicator of relative intensity of physical activity and compared with many other measures is inexpensive, easy to administer and appealing to subjects. The technique has received growing popularity as a field measure in many physical activity studies (Payne et al, 1995, 1994; Armstrong et al, 1991, 1990; Sallis et al, 1993; Durant et al 1993, 1992; Livingstone et al, 1992; Janz et al, 1992; Riddoch et al, 1991b; Freedson, 1989).

Two major issues surrounding continuous heart rate measurement are however, outstanding; Firstly, it is unclear how many days of continuous heart rate measurement are required in order to gain an accurate estimate of an individuals typical activity level. The number of days of heart rate data recorded has varied widely between researchers, ranging from 1 day (Janz et al, 1992) through to seven days (Gretebeck and Montoye, 1992). It remains an anomaly however whether limited data recordings (e.g. 3 to 4 days), as commonly employed by researchers (Payne et al, 1995, 1994; Armstrong et al, 1994, 1991, 1990; Durant, 1993,1992) can be used to judge the attainment of standards. The extent to which activity measures recorded over a few days can give a true picture of habitual activity is unclear and such measures may be inappropriate when comparing observed activity levels against current consensus activity guidelines which are expressed in terms of one week (Sallis & Patrick, 1994). Few studies have examined the variability of heart rate across test days or determined carefully the number of days necessary to yield accurate reflection of physical activity.

The consistency of heart rate activity from day to day was questioned by Durant and colleagues (1993, 1992), who examined heart rate variability in groups of children aged 3-5 and 5-7 years. Heart rate measures (mean heart rate, percent of heart rate >120b.min^{-1} and longest duration heart rate >120 b.min^{-1}) showed some variability between 2 days of measurement (intraclass correlation coefficient, 0.65-0.66). Applying the Spearman Brown prophecy formula (Fleiss, 1986; Stanley, 1971) to predict the number of days necessary to increase the intraclass correlation to at least 0.80, the authors estimated that a minimum of 4 days were required. Greatest consistency was yielded using the heart rate index "percentage of heart rate greater than 25% above resting heart rate (R=0.81, n=116) (Durant et al, 1993). Monitoring however, did not include weekend days and thus the potential variance between weekday and weekend activity was not taken into consideration. In a study of adult men, Gretebeck and Montoye (1992) examined the variability of heart rate data across 7 days. They observed that whilst the level of physical activity across weekdays was relatively stable (F=0.72, n=30, p>0.05), the inclusion of weekend data increased the variability and recommended that at least 5 to 6 days of measurement (including one weekend day) be recorded. No such studies examining variability of heart rate over a 7 day period have been conducted in children.

The second issue relates to the lack of standardized method for the interpretation of continuous heart rate data. Heart rate data can be expressed in many ways to achieve an activity index; relative to selected heart rate cut off points (Sallis, 1993; Armstrong et al, 1994, 1991,1990); relative to a resting heart rate measure (Durant et al, 1993, 1992) or resting heart rate equivalent (Atkins et al, 1995; Gretebeck &

Montoye, 1992; Janz et al, 1992; Freedson, 1989); relative to a laboratory determined "critical" or "flex" heart rate and converted to a percentage of maximal oxygen uptake (Payne et al, 1995, 1994; Livingstone et al, 1992; Riddoch et al, 1991b; Verchuur & Kemper, 1985). The objectivity of the heart rate measure is weakened by the lack of standardized protocol for translating the data series into a meaningful index of physical activity. The outcome measures are thus partly shaped by the idiosyncrasies of the interpretive method adopted and research findings are consequently somewhat unclear and inconclusive. It is necessary to evaluate which methods of heart rate data analysis can provide the most meaningful index of physical activity.

For larger scale studies and population surveys of physical activity, heart rate indices which eliminate the need for laboratory measures of oxygen uptake hold most potential. These methods primarily define light, moderate and vigorous levels of activity by the setting of arbitrary criterion heart rate levels (for example using 159 $b.min^{-1}$ to indicate vigorous activity, Armstrong et al, 1991, 1990). Heart rate can then be used to indicate intensity of activity by examining the number (and/or percentage) of recorded heart rates above these cut off points.

- **Heart rate greater than 119, 139 and 159 $b.min^{-1}$.** On the basis of laboratory treadmill studies of heart rate response to different exercise intensities, Armstrong and colleagues (1991, 1990) used a heart rate of 139 $b.min^{-1}$ to identify moderate levels of activity (this level being roughly equivalent to brisk walking in children), and 159 $b.min^{-1}$ as representative of vigorous levels of activity. They examined both total number of heart rates above the selected threshold levels and the number of sustained periods of activity (5, 10 and 20 minutes duration), favouring the latter procedure given that it is sustained aerobic activity which is of most benefit to cardiovascular fitness. It also enabled isolated heart rate peaks, which are prone to artifact, to be excluded from the analysis.

Other researchers have selected lower thresholds to indicate moderate level activity, particularly in studies of young children who, though noticeably active, may rarely achieve sustained periods with heart rate greater than 139 $b.min^{-1}$ (Durant et al, 1993, 1992; Sallis et al, 1993). The cut off level of 119 $b.min^{-1}$ has been used to assess activity in children 3-5 and 5-7 years (Durant et al, 1993, 1992) and to assess moderate activity in adolescents (Sallis et al, 1993) with the assumption that at heart rates below 120 $b.min^{-1}$ children are engaged in resting, non-locomotor or very slow locomotor activities, and that at heart rates above this level children are involved in walking activity or greater.

- **Heart rate activity relative to resting heart rate levels.** The straight "cut off" method for identifying light, moderate and vigorous levels of activity (eg 139 $b.min^{-1}$ for moderate level activity) has been criticized for not accounting for individual differences in resting heart rate (RHR, $b.min^{-1}$) and heart rate response to exercise. A child with a high level of aerobic fitness may be able to perform an equivalent workload at a lower heart rate than an unfit child. In order to account for this, researchers have examined heart rate levels relative to resting heart rate (Durant et al, 1993, 1992). Durant and colleagues (1993) examined heart rate activity in groups of young children (3-7 years) by various methods including the number of heart rates greater than RHR+20 $b.min^{-1}$, RHR+30 $b.min^{-1}$, the percentage of heart rates greater than 25% above RHR and the percentage of heart rates greater than 50% above RHR. Of each of these criterion measures, the 25%RHR level provided the best indicator of relative activity levels and was shown to be extremely stable across 2 separate test days (between day intraclass correlation coefficient; R=0.81, n=116). Whilst this index of heart rate activity looks extremely promising, this work has not been replicated and the technique has not been applied to older groups of children. One likely drawback of the technique is that all the cut off levels adopted by Durant and colleagues constitute fairly low levels of heart rate intensity (e.g. if RHR is 70 $b.min^{-1}$, then RHR+20 examines all heart rates greater than 90 $b.min^{-1}$, RHR+30 examines all heart rates greater than 100 $b.min^{-1}$and likewise, 125% RHR= 87.5 $b.min^{-1}$). Higher levels may be necessary to discriminate patterns of activity in older children, but to date, this has not been explored.

- **Heart rate relative to a resting heart rate equivalent.** Resting heart rate can be measured by a variety of different methods and varies according to many factors including breathing pattern, posture, the test environment and the time of day (Neyland, 1995; Kitney & Rompelman, 1980). Whilst there is no standardised procedure, one method which is reported to provide the most consistent resting heart rate index is to record heart rate first thing in the morning, with the subject in a fasted state and prior to any activity (Durant et al, 1993, 1992; Spurr & Reina, 1990). It is a complex and time consuming procedure and many researchers have sought alternatives. Continuous heart rate data obviously contains detailed record of heart rate fluctuations throughout the day and will include record of heart rate during habitual rest periods. Various techniques have been developed which utilise this continuous heart rate data to identify a resting heart rate equivalent including, mean heart rate during sleep (Atkins et al, 1995), mean of the 50 lowest heart rates of the day (Gretebeck & Montoye, 1992) and mean of all heart rates within 3 beats of the lowest recorded heart rate (Janz et al, 1992; Freedson, 1989). None of the procedures have been rigorously validated against actual resting heart rate measures but they present an interesting new approach to heart rate data analysis and warrant further investigation.

- **Heart rate greater than 75% heart rate reserve.** Heart rate reserve (HRR) takes differences in resting heart rate into consideration and furthermore accounts for individual differences in maximal heart rate. It relates to the available heart rate range within which heart rate can vary (resting heart rate to maximal heart rate). Whilst Atkins and coworkers (1995) examined heart rate activity in children using 75% of heart rate reserve, they found that very few children actually attained these levels of intensity (7% of boys and none of the girls studied achieved a single 20 minute period with heart rate sustained above 75% HRR). This finding is perhaps not surprising given that this is level of activity is actually quite vigorous (If RHR=70 and maximum HR=206, then 75%HRR=172 $b.min^{-1}$). Sixty percent HRR has also been used (Janz et al, 1992) but again the duration of activity at this level appears to very limited (8 mins per day for girls and 11 mins per day for boys, n=37 pubescent children). Lower percentages of heart rate reserve may be more appropriate in children.

- **Total number of heart rates greater than threshold.** Sustained periods of activity at moderate to vigorous intensity may be necessary for fitness benefit (ASCM, 1990), but the level of activity necessary for health benefit is less clearly defined. Several authors have argued that it is total energy expenditure which is the most important aspect of physical activity for health and if this is the case, even activity of relatively short duration (<5 minutes) warrants consideration (indeed however brief the activity, it demands energy and all energy consumption adds up over the day). Many researchers have thus examined the total number of heart rates (or percentage of heart rates over the recording period) which have been above selected threshold levels, irrespective of the length of time for which the elevated heart rates have been sustained (Durant et al, 1993, 1992; Livingstone et al, 1992; Spurr & Reina, 1990). As stated before, this method is more likely to include occasional erroneous heart rate readings (eg isolated heart rate peaks due to electrical interference) but, provided these are negligible, it provides an important measure of general overall activity.

The primary aim of this study was to conduct an exploratory investigation of heart rate monitoring measurement and analysis techniques. Particular focus was placed on examining the day to day variability of heart rate activity across 7 days of measurement, thus determining the number of days necessary to gain reasonable estimate of a child's total weekly activity. Secondly, the study was used to evaluate the extent to which various popular methods of heart rate data analysis compare against physical activity assessed by self report diary and which, if any, provide the best index of actual physical activity levels.

The following methods of heart rate data analysis were examined:-

◊ Mean, maximum and minimum daily heart rate ($b.min^{-1}$)

◊ Lowest sustained daily heart rate (tickover heart rate, TOHR[9])

◊ Number of 5, 10 and 20 minute periods, with heart rate greater than 119, 139 and 159 $b.min^{-1}$

◊ Number of 5, 10 and 20 minute periods with heart rate greater than 20, 30 and 50 beats above tickover heart rate

◊ Number of 5, 10 and 20 minute periods with heart rate greater than 125, 150 and 175% of tickover heart rate

◊ Number of 5, 10 and 20 minute periods with heart rate greater than 50% and 75% of heart rate reserve

◊ Total number of heart rates greater than tickover plus 20, 30 and 50 $b.min^{-1}$, total number of heart rates greater than 125, 150 and 175% tickover and total number of heart rates greater than 50 and 75% heart rate reserve.

---

[9] To account for individual differences in heart rate response to exercise and in particular, differences in resting heart rate levels, several studies have attempted to establish a daily baseline heart rate and evaluated activity levels relative to this measure. Methods for identifying baseline heart rate from continuous data include the mean of the 50 lowest heart rates of the day (Gretebeck & Montoye, 1992), mean of all heart rates within 3 beats of the lowest recorded heart rate (Janz et al, 1992; Freedson, 1989) and mean heart rate during sleep (Atkins et al, 1995). This study identified baseline heart rate (labelled as tickover heart rate, TOHR) as the lowest 15 minute moving average from each day of monitoring. This method was selected in view of findings that isolated minimum heart rate values are often prone to artifact and are biased toward underestimation of resting heart rate (Durant et al, 1992) and also to avoid the recording of heart rate during sleep which would likely reduce the number of days subjects would be willing to wear the monitors. The tickover method developed here provided an individualized measure of rested state heart rate during waking hours. A pilot investigation showed strong correlation between TOHR and resting heart rate (r=0.65-0.98) (See Appendix II).

5.2 METHOD

(a) General Procedures

Twenty eight school children (14 males, 14 females), mean age 13.9 +/- 0.5 years, were recruited. All children were taking part in a larger scale survey of fitness and physical activity patterns in children and were selected on the basis of the quality of their heart rate and activity diary data. Each child returned 6 to 7 days of heart rate data, accompanied by detailed diary account of their activities over that period.

Anthropometric measures (height and weight) were recorded with children wearing light clothing (PE kit) and shoes removed. The same trained observer also assessed skinfold thickness measures (subscapular and triceps), using Harpenden skinfold calipers and following the techniques described by Lohman and colleagues (1991). All children performed 2 repeat shuttle run tests (National Coaching Foundation, Leeds), 1-2 weeks apart and the best score recorded (number of laps completed and maximal shuttle run speed, $km.h^{-1}$). Performance on the shuttle run test was used to estimate peak oxygen uptake (VO_2 Peak, $ml.Kg^{-1}.min^{-1}$) using prediction equations specially formulated for this age group (McVeigh et al, 1995, Appendix 4).

(b) Continuous heart rate monitoring

Continuous heart rate monitors (Polar Electro PE4000, Finland), were worn for 7 consecutive days (Monday to Sunday) and used in conjunction with a self report activity diary (adapted from Durnin & Passmore, 1967). Transmitters were fixed to the chest using either disposable electrodes or an electrode belt, (depending on subject preference) and the monitors set to record heart rate every 60 seconds. The monitors were worn over a targeted 12 hour continuous period from 8:30 am to 8:30 pm daily (or earlier if children took part in early morning/late evening activity)[10].

Measurement procedures were piloted previously in a group of 24 children (12 girls, 12 boys). A number of steps were employed to reduce loss of data through electromagnetic interference (due to close proximity with other monitors or electromagnetic appliances), and loss of data due to removal of the electrodes (most commonly due to children developing a mild skin irritation after extended wear or due to slippage during vigorous activities). Children were divided into small, mixed sex, test groups (n=6-10 per week). An introductory session was held during which the set up and functioning of the monitors was demonstrated in full and each child given opportunity to practice fitting and operating them. An instructional hand out was also provided for easy reference (See Appendix III). Children were instructed to avoid tampering with the monitor controls during the test period and to avoid, where possible, close contact with each other or any powerful electrical equipment whilst wearing the monitor. Projected activities for the week were examined using school timetables and on days for which vigorous sports or activities (e.g. rugby) were planned, electrode attachments were reinforced with additional strapping (elasticized

[10] The Polar Electro PE4000 supersedes the older PE3000 model commonly used in many studies of heart rate and activity patterns (Livingstone et al, 1992; Armstrong et al, 1990, 1991). This latest model has several invaluable features which make it a much more adaptable and valid tool for assessing habitual patterns of activity:

- It is capable of storing up to 8 separate data files and thus can be switched off and on between designated activity periods.
- It has a smaller more compact design for both the transmitter and watch components making it more attractive to wear and user friendly.
- Data transfer to computer is improved by more effective interfacing procedures

bandage). All children were visited at least once a day by a trained researcher who downloaded previously stored data to computer and checked to ensure there were no problems with monitor programming and/or data storage.

Fig. 5.1: Children wearing the Polar Electro Heart Rate Monitors

(c) Seven day activity diary

All children were issued with a 7 day activity diary. During the pilot investigation this was given in the form of separate A4 sheets breaking the day down into morning, afternoon and evening sections (Lange Anderson et al, 1978). Whilst children found these easy to complete, the loose leaf format meant that, on occasions, children lost them before they could be returned to the tester. For the purposes of the main study, a small A6, 7 day booklet was developed. These diaries, similar to those recommended by Durnin & Passmore (1967), used large squares to represent each hour of the day and small squares covering minute by minute periods. This booklet was more resilient and distinctive than loose sheets of paper and was designed to fit comfortably into the pocket of a school blazer or bag (Appendix III).

Activity diaries can be reported directly in terms of mode, frequency and/or duration of activity or converted to a measure of energy expenditure using predictive tables of energy cost for specific activities (Brooks & Fahey, 1985; Durnin & Passmore, 1967). Since energy cost can vary widely between individuals, the latter method does not always provide accurate estimate of calorific expenditure and can be subject to considerable error (Laportes et al, 1985; Montoye & Taylor, 1984). Different diary formats are also available (Riddoch et al, 1992b; Bouchard et al, 1983; Lange Anderson et al, 1978; Durnin & Passmore, 1967). The format devised by Durnin and Passmore (1967) was selected in preference to others given it's compact and simple layout. Direct reporting of type and duration of activity is easy for children to comprehend and does not require children to make complex subjective judgement regarding the intensity of their activity. Whilst diaries based on children's self report of activity intensity have been used (Bouchard et al, 1983), the validity of the measure may be harder to establish and the level of reporting error may be greatly increased (Sallis, 1991).

Children were instructed to complete the minute by minute diary reports as frequently as they could, taking particular care to note down the exact times and duration of any activity and using simple code letters to signify the type of activity performed. It was stressed that they should try to make a clear distinction between the duration of actual activity (e.g walking, running, football, sitting) as opposed to the length of the exercise session (eg. a one hour P.E. class). Activity diaries were then analysed directly in terms of the reported time spent in moderate to vigorous activity without convertion to estimated energy expenditure. This "significant activity time" was identified as any activity lasting 5 minutes or longer and which was equivalent to a brisk walk or above (eg. fast walk, hill walk, jog, run, tennis, football, aerobics, dance). The duration of each of individual active bout was extracted from the diary reports and the total for the week recorded as a weekly activity score for each child (reported seven day activity, SDA, in minutes).

(d) Statistical analysis

Descriptive statistics (age, height, weight, skinfold thickness, shuttle run performance, predicted VO_2 Peak and physical activity measures) were determined for both males and females. Differences between the sexes were determined using independent sample t-tests. The Mann Whitney U test for non-parametric data was used for those measures where a normal distribution was not indicated (common for many of the heart rate activity indices). Variability of each of the selected heart rate activity indices across the seven days of measurement was determined by intraclass correlation coefficient.

Analysis was then extended to examine the relationship between each of the heart rate activity indices and reported activity levels (SDA). All measures were evaluated on the basis of their Pearsons product moment correlation with reported SDA. The most powerful of the measures were also examined according to Spearman's rank correlation.

(e) Heart rate data processing

Data for each of the recorded days was transferred directly from the Polar Electro Sport Tester database to a standard spreadsheet software format (Excel), where daily recordings were collated to create a "weeklong" file for each individual (See Figure 5.2). Alternate columns (i.e. B,D,F,H,J,L, and N) represented each of the 7 days of the week with B representing Monday through to N for Sunday. Data recordings where the full days data was contained on two separate files (due to subject having removed the monitor briefly for showering etc.) were joined, paying close attention to the temporal sequencing of the data list. For any minutes missed between the two part-day files, heart rate readings were averaged across the 2 end values.

Once collated, the week files were screened for any obvious erroneous data. The first 10 numerical values on each days data file contained the Polar Electro codes and information regarding the settings of the monitors (Fig 5.2, inset). These values were preserved in order to identify the precise start time and watch settings for each of the recorded days. Similarly the 4 entries at the end of each file contained stop codes along with details of the recording duration. Again these were maintained on the data spreadsheet. Additional marker codes occasionally appeared in the middle of the data recordings. These tended to have been placed accidentally by subjects but were easily identified by the code values 252 and 253 and were removed from the data recording.

For heart rate values >210 (suspected cause - electrical interference by external device) and for values <50 (suspected cause - faulty transmission from transmitter to the microcomputer watch receiver) data values on either side of the artifact were, as for missing data, averaged to the nearest whole number (Figures 5.3 and 5.4). Because subjects were selected on the basis of the quality of their heart rate data, the percentage of missing data for the study sample was low. All children provided 6 to 7 days of heart rate data (six days, n=10; seven days, n=18). Those children who returned six days of data were only accepted on the basis of their diary reports which indicated no significant moderate to vigorous activity had been undertaken during the missing day. From a target of 196 days (7 days for each child), 186 were achieved (95%) and for all recorded days, missing data constituted just 2% of the total readings.

Fig 5.2 Example of a subject's week long data spreadsheet file

Cell No.	A	B	C	D	E	F	G	H	I	
1		251	mon	251	tues		wed		thurs	and so on -->
2		60		60						
3		1		2						
4		240		240						
5		40		40						
6		240		235						
7		40		40						
8		92		84						
9		07.25.40		07.38.25						
10		0		0						
11		89		80						
12		94		88						
13		87		83						
14		112		90						
15		120		98						
16		109		101						
17		116		97						
18		122		85						
19		129		79						
20		134		81						
21		138		95						
22		135		99						
23		127		92						
24		121		90						
25		108		105						
.		.		.						
.		.		.						
.		.		.						
.		.		.						
.		.		.						
.		79		106						
.		80		98						
.		85		101						
.		88		87						
.		94		85						
.		91		88						
.		100		78						
.		106		92						
.		101		75						
.		87		85						
.		254		90						
.		98		95						
.		13.34.15.6		254						
.		255		92						
.		.		13.36.12.5						
.		.		255						
990		.		.						

POLAR ELECTRO MARKER CODES

251	Start code
60	Recording interval (5,15, 60 sec)
1	File number (1-8)
240	Upper limit 1 (training zone)
40	Lower limit 1 (training zone
240	Upper limit 2 (training zone)
40	Lower limit 2 (training zone)
92	First heart rate measure
07.25.40	Start time
0	AM/PM indicator (0/1 resp.)
252	Marker code
253	Marker code (watch feature which allows certain time intervals to be identified)
254	End code
98	Final heart rate measure
13.34.15	Total recording time (hrs/min/sec)
255	End code

Fig 5.3 Sample Heart Rate Data Trace (before screening for erroneous data)

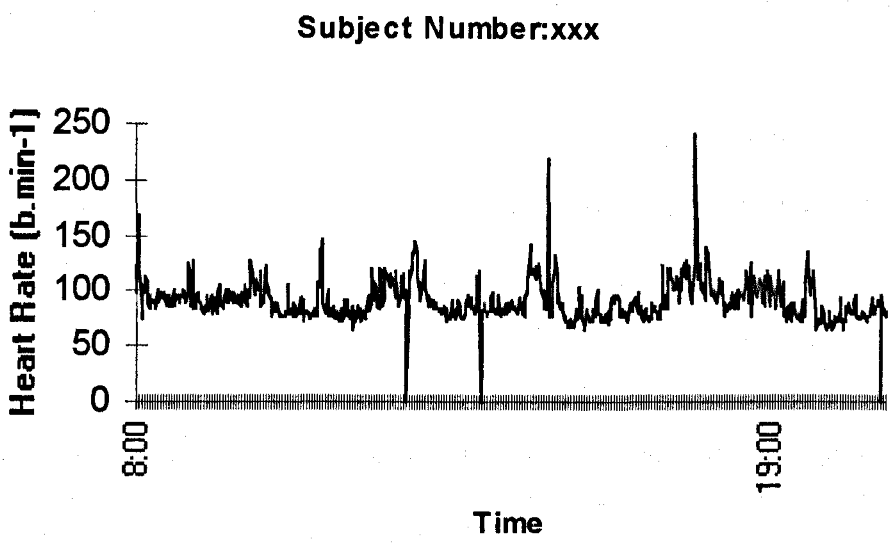
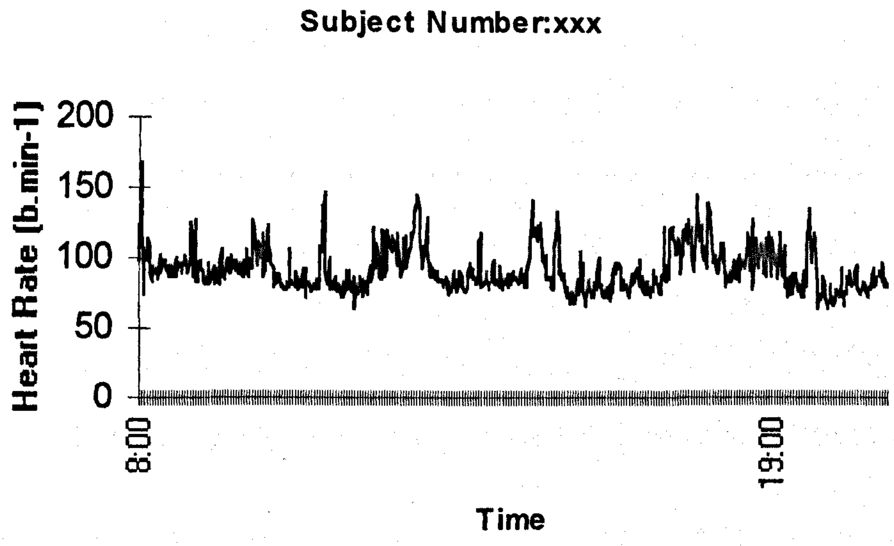


Fig 5.4 Sample Heart Rate Data Trace (after screening)



Several computational spreadsheets were set up to identify specific features within the heart rate data:-

a) the time of each heart rate reading. Identifying the time at which each data entry occurred, (relative to the starting time specified in the initial code data) enabled opportunity for all heart rate readings to be matched with specific events from the activity diaries as and when required.
b) the number of 5, 10 and 20 minute periods with HR>119,139 & 159 $b.min^{-1}$.
c) summary measures (mean, maximum and minimum daily heart rate) and the "tickover" value (lowest 15 min moving average for each day of recording)
d) the total number of recorded heart rates and the number of sustained 5, 10 and 20 minute periods with heart rate greater than tickover plus 20, 30 and 50 $b.min^{-1}$
e) the total number of recorded heart rates and the number of sustained 5, 10 and 20 minute periods with heart rate greater than 125, 150 and 175% tickover heart rate.
f) the total number of recorded heart rates and number of 5,10 and 20 minutes periods with heart rate greater than 50% and 75% of heart rate reserve.

Spreadsheet a: *Data time sequencing*

This spreadsheet was used to identify the time at which each data recording occurred. Each subject's week long file was imported in turn to this spreadsheet and the time sequencing information saved to a new file. Commands to identify the time at which each heart rate data value occurred were set in alternate columns C, E, G, I, K, M, and O. On the subject week files, start time codes were always located in row 9 (eg B9 for Monday, D9 for Tuesday and so on). On the computational spreadsheet, this code time was copied to the adjoining column and converted from numerical to time format (Figure 5.5). The time of occurrence for each data entry was then determined relative to this start time and displayed in the adjoining column for each of the days recorded.

Fig 5.5 Example of a subjects week long data spreadsheet file - after processing to determine the time at which each entry occurred.

Cell No.	A	B	C	D	E	F	G	H		
1		251	mon		tues		wed		thurs	---->
2		60								
3		5								
4		240								
5		15								
6		235								
7		10								
8		92								
9		07.25.4007.25								
10		0								
11		89	07.26							
12		94	07.27							
13		87	07.28							
14		112	07.29							
15		120	07.30							
16		109	07.31							
17		116	07.32							
18		122	07.33							
19		129	07.34							
20		134	07.35							
21		138	07.36							
22		135	07.37							
23		127	07.38							
24		121	07.39							
25		108	07.40							
.		.	etc.							
.		.	.							
.		.	.							
.		.	.							
.		.	.							
.		.	.							
.		.	.							
.		79	21.01							
.		80	21.02							
.		85	21.03							
.		88	21.04							
.		94	21.05							
.		91	21.06							
.		100	21.07							
.		106	21.08							
.		101	21.09							
.		87	21.10							
.		254	.							
		98	.							
.		13.34.15.6		.						
.		255	.							
.		.	.							
.		.	.							
990		.	.							

Spreadsheet b: *Determining the number of 5, 10 and 20 minute periods with heart rate greater than 119, 139 and 159 b.min^{-1}.*

To compute the number of 5, 10 and 20 minute periods with heart rate sustained above 119, 139 and 159 beats per minute, a computation spreadsheet was constructed into which each data file was imported, processed, and the results copied to a new file using a series of computer macros.

Each day's data was imported to column A (Figure 5.6). In column B each data entry was processed in turn and displayed as a 1 or a zero depending on whether it was greater or less than 119 b.min^{-1}. In column C, all groups of ones were added cumulatively indicating the duration of the periods for which heart rates were greater than 119 b.min^{-1}. The adjoining 3 columns were then used to identify the number of 5, 10 and 20 mins blocks respectively. These were totaled and the result displayed in labeled cells (C5 to K5). A similar process was used to identify the number of 5, 10 and 20 minute periods greater than 139 and 159 b.min^{-1} using appropriately adjusted formula.

The results displayed were later copied and pasted to a second spreadsheet where the processed data for all seven days for each individual were collated.

Fig 5.6: Determining the no. of sustained active periods,>119,139 & 159 b.min^{-1}

Cell No.	A	B	C	D	E	F	G	H		
1	251									
2	60									
3	5		>119bpm			>139bpm			>159bpm	
4	240		5mins	10min	20mins	5mins	10mins	20mins	5 mins --->	
5	15		3	1	0	2	1	0	0	
6	235									
7	10									
8	92									
9	09.15.25			(5min)	(10min)	(20min)			(5min)	(10 min)
10	0	(>119)	counter	blocks	blocks	blocks	(>139)	counter	blocks	blocks ---->
11	100	0	0	0	0	0	0	0	0	0
12	118	0	0	0	0	0	0	0	0	0
13	145	1	1	0	0	0	1	1	0	0
14	152	1	2	0	0	0	1	2	0	0
15	150	1	3	0	0	0	1	3	0	0
16	140	1	4	0	0	0	1	4	0	0
17	156	1	5	0	0	0	1	5	0	0
18	160	1	6	0	0	0	1	6	0	0
19	158	1	7	0	0	0	1	7	0	0
20	146	1	8	0	0	0	1	8	0	0
21	142	1	9	0	0	0	1	9	0	0
22	144	1	10	0	0	0	1	10	0	0
23	141	1	11	0	0	0	1	11	2	1
24	139	1	12	0	0	0	0	0	0	0
25	127	1	13	0	0	0	0	0	0	0
26	141	1	14	0	0	0	1	1	0	0
27	120	1	15	3	1	0	0	0	0	0
28	118	0	0	0	0	0	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	72	0	0	0	0	0	0	0	0	0
.	77	0	0	0	0	0	0	0	0	0
.	81	0	0	0	0	0	0	0	0	0
.	84	0	0	0	0	0	0	0	0	0
.	94	0	0	0	0	0	0	0	0	0
.	93	0	0	0	0	0	0	0	0	0
.	108	0	0	0	0	0	0	0	0	0
.	102	0	0	0	0	0	0	0	0	0
.	254									
.	98									
.	12.11.45.3									
.	255									
.	.									
990	.									

Spreadsheet c: *Identifying summary heart rate statistics and the "tickover" heart rate.*

Mean, maximum and minimum daily heart rate were computed using the appropriate commands and reference cells within the spreadsheet. Tickover heart rate, defined as the lowest mean heart rate achieved over a 15 minute period of quite rest, required more extensive data processing. The spreadsheet designed to compute the daily tickover values is illustrated in Figure 5.7. Fifteen minute moving averages were determined for the day's heart rate readings and listed in column B. The minimum value from column B was then identified and displayed in a reference cell along with details of the time at which the lowest tickover value occurred.

Fig 5.7: Determining the minimum 15 min moving average ("Tickover values").

Cell No.	A	B	C	D	E	F	G	H	
1	251								
2	60		Mean HR		Min HR		Max HR		TOHR & time
3	5		=mean		=minimum		=maximum		=minimum
4	240		value (A11		value (A11		value (A11		value from
5	15		to data end)		to data end)		to data end)		column b
6	235								
7	10								
8	92	15 min							
9	09.15.25	average	Time						
10	0								
11	100	137	7.26						
12	118	139	7.27						
13	145	139	7.28						
14	112	138	7.29						
15	120	147	7.30						
16	140	152	7.31						
17	156	153	7.32						
18	160	150	7.33						
19	158	146	7.34						
20	146	142	7.35						
21	142	139	7.36						
22	144	138	7.37						
23	141	.	.						
24	139	.	.						
25	127	.	.						
26	141	.	.						
27	120	.	.						
28	118	.	.						
.	.	.	.						
.	.	.	.						
.	96	97	.						
.	98								
.	92								
.	90								
.	88								
.	72								
.	77								
.	81								
.	84								
.	94								
.	93								
.	97								
.	90								
.	108								
.	102								
.	254								
	98								
.	12.11.45.3								
.	255								
.	.								
990	.								

Spreadsheet d: *the total number of recorded heart rates and the number of sustained 5, 10 and 20 minute periods with heart rate 20 b.min^{-1}, 30 b.min^{-1} and 50 b.min^{-1} greater than the tickover value.*

Format was similar to that used for the data processing for sustained periods with heart rate greater than 119, 139 and 159 b.min^{-1}. Daily data was imported to column A. Individual tickover values were determined previously and copied to cell B2. All calculations in the adjoining columns were then performed in reference to this value. Column C determined whether each heart rate data entry was greater or less than the tickover value plus 20 and recorded it as a one or a zero accordingly. column D added the "1" entries cumulatively and columns E,F and G determined the number 5, 10 and 20 minute blocks. This was repeated, on the same spreadsheet, for tickover plus 30 and tickover plus 50. Results were displayed across Row 5 and later copied and pasted to a new file where the full weeks processed data was collated.

Spreadsheet e: *the total number of recorded heart rates and the number of sustained 5, 10 and 20 minute periods with heart rate 25, 50 and 75% above the tickover value.*

This spreadsheet had exactly the same format as the previous one. Calculations determined the specified percentages of the tickover values as opposed to adding specified amounts to the tickover.

Spreadsheet f: *the total number of recorded heart rates and the number of sustained periods with heart rate greater than 150% and 175% heart rate reserve.*

This again had similar format to the previous spreadsheets. As before tickover values were imported into cell B2. Maximum heart rate was determined from the formula , 220-age in cell B3 and then formula set up to establish heart rate reserve in cell B4. Percentages of heart rate reserve were determined by referencing formula to this cell.

Fig 5.8 Calculating sustained periods with HR>20,30 & 50 $b.min^{-1}$ above tickover

Cell No.	A	B	C	D	E	F	G	H
1	251	tickover						
2	60	(eg.78)						
3	5							
4	240							
5	15			TOHR +20				TOHR +30
6	235			5mins	10min	20mins	5mins	10mins --->
7	10			3	1	0	2	1
8	92							
9	09.15.25			(5min)	(10min)	(20min)		
10	0	(>TOHR+20)	counter	blocks	blocks	blocks	--->	
11	100	1	1	0	0	0		
12	118	1	2	0	0	0		
13	145	1	3	0	0	0		
14	112	1	4	0	0	0		
15	120	1	5	0	0	0		
16	140	1	6	0	0	0		
17	156	1	7	0	0	0		
18	160	1	8	0	0	0		
19	158	1	9	0	0	0		
20	146	1	10	0	0	0		
21	142	1	11	0	0	0		
22	144	1	12	0	0	0		
23	141	1	13	0	0	0		
24	139	1	14	0	0	0		
25	127	1	15	0	0	0		
26	141	1	16	0	0	0		
27	120	1	17	0	0	0		
28	118	1	18	0	0	0		
29	100	1	19	3	1	0		
30	97.	0	0	0	0	0		
31	99	1	1	0	0	0		
32	93	0	0	0	0	0		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	72	0	0	0	0	0		
.	77	0	0	0	0	0		
.	81	0	0	0	0	0		
.	84	0	0	0	0	0		
.	94	0	0	0	0	0		
.	93	0	0	0	0	0		
.	108	1	1	0	0	0		
.	102	1	2	0	0	0		
.	254							
	98							
.	12.11.45.3							
.	255							
990	.							

Fig 5.9 Calculating sustained periods with HR > 50 & 75% of heart rate reserve

Cell No.	A	B	C	D	E	F	G	H
1	251	tickover (lowest 15min moving average (eg.78)						
2	60	max HR (220-age) (eg.206)						
3	5	HRR (maxHR-TOHR)) (eg 128)						
4	240	50%HRR + TOHR (eg 142)						
5	15				50% HRR			75%HRR
6	235			5mins	10min	20mins	5 mins	10 mins
7	10			3	1	0	2	1
8	92							
9	09.15.25			(5min)	(10min)	(20min)		
10	0	(>B4)	counter	blocks	blocks	blocks		
11	100	0	0	0	0	0		
12	118	0	0	0	0	0		
13	145	1	1	0	0	0		
14	112	0	0	0	0	0		
15	120	0	0	0	0	0		
16	140	0	0	0	0	0		
17	156	1	1	0	0	0		
18	160	1	2	0	0	0		
19	158	1	3	0	0	0		
20	146	1	4	0	0	0		
21	142	0	0	0	0	0		
22	144	1	1	0	0	0		
23	141	0	0	0	0	0		
24	139	0	0	0	0	0		
25	127	0	0	0	0	0		
26	141	0	0	0	0	0		
27	120	0	0	0	0	0		
28	118	0	0	0	0	0		
29	100	0	0	0	0	0		
30	97.	0	0	0	0	0		
31	99	0	0	0	0	0		
32	93	0	0	0	0	0		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	.	.	.	.	.	.		
.	72	0	0	0	0	0		
.	77	0	0	0	0	0		
.	81	0	0	0	0	0		
.	84	0	0	0	0	0		
.	94	0	0	0	0	0		
.	93	0	0	0	0	0		
.	108	0	0	0	0	0		
.	102	0	0	0	0	0		
.	254							
	98							
.	12.11.45.3							
.	255							
990	.							

5.4 RESULTS

Summary statistics by gender are presented in Table 5.1 (anthropometric and physical fitness measures) and Table 5.2 (physical activity measures) below:

Table 5.1: Summary statistics by gender (mean +/-sd)

	Males (n=14)		Females (n=14)	All (n=28)
Age (yrs)	13.9 (0.4)		13.9 (0.3)	13.9 (0.4)
Height (cms)	162.8 (9.4)		162.4 (7.1)	162.6 (8.2)
Weight (Kg)	53.3 (8.8)		54.6 (8.7)	54.0 (8.6)
Sum of Skinfolds[$]	19.3 (5.0)	*	24.9 (7.0)	22.1 (6.6)
Maximal shuttle run (no. of laps)	72.2 (17.0)	*	52.4 (21.2)	61.9 (21.4)
Maximal shuttle speed ($km.h^{-1}$)	12.3 (0.8)	*	11.3 (1.1)	11.7 (1.1)
Predicted VO_2 peak ($ml.min^{-1}\ Kg^{-1}$)	53.8 (8.8)	*	45.9 (8.2)	49.7 (7.7)
Predicted VO_2 peak ($l.min^{-1}$)	2.91 (0.5)	*	2.49 (0.5)	2.69 (0.5)

* denotes significant difference between gender groups, p<0.05
[$] Sum of triceps and subscapular skinfolds

In agreement with the findings from the previous phase, there was no significant difference between the sexes in terms of age, height and weight (t=-0.33, t=0.14, t=-0.39, respectively, df=26, p>0.05, all not significant) but males had significantly better performance on the shuttle run test, higher predicted VO_2 peak and lower skinfold thickness measures (Shuttle run performance (no. of laps), t=2.67, df=25; maximal shuttle run speed, t=2.75, df=25; predicted VO_2 peak, t=3.06, df=25; sum of triceps and subscapular skinfolds, t=-2.47, df=26; p<0.05).

Table 5.2: Summary statistics for the activity measures (mean +/- sd)

	Males (n=14)	Females (n=14)	All (n=28)
Reported seven day activity, SDA (no. of mins)	381.1 (174.1)	301.8 (170.6)	341.4 (173.9)
Mean duration of heart rate recording (mins/day)	727.1 (49.1)	747 (60.0)	737.1 (54.8)
Mean daily HR ($b.min^{-1}$)	97.3 (7.7)	97.4 (4.8)	97.4 (6.30
Maximum daily HR ($b.min^{-1}$)	183.5 (10.9)	185.8 (9.7)	184.7 (10.2)
Minimum daily HR ($b.min^{-1}$)	63.3 (6.5)	62.4 (5.0)	62.9 (5.7)
Tickover HR ($b.min^{-1}$)	74.0 (7.7)	73.0 (6.0)	73.3 (6.8)

The quality of the heart rate data return was high with a mean recording duration time of over 12 hours per day (737 +/-55 minutes). Each day of heart rate recording was matched by detailed daily written account of activity contained in the activity diaries. All reported periods of moderate to vigorous activity (minimum 5 minutes duration) were summated for the week providing each child with a simple score of reported seven day activity time (SDA, minutes). Mean reported SDA was higher for males than females, (Males, 381+/-174 mins; Females, 302 +/-171 mins), but the rank distribution did not reach statistical significance ($z=1.15$, $p=0.251$). As evidenced by the large standard deviations, both males and females showed large variation in the activity levels of individuals (range for males = 105-660 minutes, range for females = 60-600 mins). Mann Whitney U tests indicated no significant sex differences for any of the heart rate measures (Table 5.3). Boys tended to have higher scores for the higher intensity measures (especially, HR>119,139 & 159$b.min^{-1}$) whilst girls tended to have higher scores for the total heart rate measures. Overall, physical activity levels for males and females were similar.

Table 5.3: Descriptive statistics for HR activity indices, mean per week (+/-sd).

Activity Index	Males		Females
No. of 5 min periods, HR>119 b.min^{-1}	71.9 (52.4)		57.5 (35.8)
No. of 10 min periods, HR>119 b.min^{-1}	24.0 (19.1)		16.6 (12.1)
No. of 20 min periods, HR>119 b.min^{-1}	7.2 (5.8)		3.2 (3.7)
No. of 5 min periods, HR>139 b.min^{-1}	18.9 (14.0)		13.1 (12.8)
No. of 10 min periods, HR>139 b.min^{-1}	6.6 (5.8)		3.0 (4.2)
No. of 20 min periods, HR>139 b.min^{-1}	2.2 (2.3)		0.9 (1.9)
No. of 5 min periods, HR>159 b.min^{-1}	3.4 (3.5)		3.0 (4.7)
No. of 10 min periods, HR>159 b.min^{-1}	0.9 (1.3)		0.5 (0.9)
No. of 20 min periods, HR>159 b.min^{-1}	0.1 (0.3)		0.1 (0.3)
No. of 5 min periods, HR>TOHR+20 b.min^{-1}	283.0 (87.2)		305.4 (111.2)
No. of 10 min periods, HR>TOHR+20 b.min^{-1}	109.0 (41.7)		114.9 (48.8)
No. of 20 min periods, HR>TOHR+20 b.min^{-1}	38.4 (18.8)		38.8 (21.7)
No. of 5 min periods, HR>TOHR+30 b.min^{-1}	156.5 (65.3)		167.6 (82.9)
No. of 10 min periods, HR>TOHR+30 b.min^{-1}	56.3 (27.0)		57.8 (33.4)
No. of 20 min periods, HR>TOHR+30 b.min^{-1}	18.4 (11.1)		17.4 (13.7)
No. of 5 min periods, HR>TOHR+50 b.min^{-1}	43.7 (29.0)		45.2 (39.0)
No. of 10 min periods, HR>TOHR+50 b.min^{-1}	14.0 (11.8)		12.4 (12.2)
No. of 20 min periods, HR>TOHR+50 b.min^{-1}	4.0 (4.0)		2.8 (3.9)
Total No. of heart rates, HR>TOHR+20 b.min^{-1}	2148.4 (446.5)		2365.4 (621.9)
Total No. of heart rates, HR>TOHR+30 b.min^{-1}	1369.2 (388.1)		1523.6 (532.4)
Total No. of heart rates, HR>TOHR+50 b.min^{-1}	499.3 (228.0)		572.0 (336.4)
No. of 5 min periods, >125% TOHR	312.1 (100.4)		348.0 (138.1)
No. of 10 min periods, >125% TOHR	121.4 (46.9)		140.6 (65.6)
No. of 20 min periods, >125% TOHR	44.4 (20.7)		47.3 (27.6)
No. of 5 min periods, >150% TOHR	102.8 (50.2)		119.6 (78.1)
No. of 10 min periods, >150% TOHR	35.1 (20.2)		38.8 (28.7)
No. of 20 min periods, >150% TOHR	10.4 (7.8)		11.1 (11.2)
No. of 5 min periods, > 175% TOHR	32.6 (25.9)		37.4 (39.5)
No. of 10 min periods,>175% TOHR	10.7 (11.3)		9.4 (12.1)
No. of 20 min periods, >175% TOHR	3.1 (3.7)		2.0 (3.8)
Total No. of heart rates, HR>125% TOHR	2300 (514.1)		2593.0 (740.0)
Total No. of heart rate, HR>150% TOHR	976.7 (384.1)		1159.4 (567.7)
Total No. of heart rates, HR>175% TOHR	391.9 (223.9)		491.5 (365.0)
No. of 5 min periods, >50% HRR	16.9 (12.2)		13.6 (15.9)
No. of 10 min periods, >50% HRR	5.6 (5.1)		3.4 (5.8)
No. of 20 min periods, >50% HRR	1.6 (1.6)		0.9 (2.1)
No. of 5 min periods, >75% HRR	0.7 (1.0)		1.6 (3.0)
No. of 10 min periods, >75% HRR	0.1 (0.4)		0.4 (0.7)
No. of 20 min periods, >75% HRR	0.0 (0.0)		0.0 (0.0)
Total No. of heart rates, > 50% HRR	230.3 (129.4)		242.1 (186.6)
Total No. of heart rates, > 75% HRR	30.7 (18.2)		39.9 (39.7)

Table 5.4: Correlation between heart rate activity indices and SDA.

Activity Index	Males	Females	All
Mean daily HR ($b.min^{-1}$)	0.31	0.05	0.19
Maximum daily HR ($b.min^{-1}$)	0.49	0.53*	0.47*
Minimum daily HR ($b.min^{-1}$)	0.29	-0.48	-0.02
Tickover heart rate ($b.min^{-1}$)	0.19	-0.51	-0.09
No. of 5 min periods, HR>119 $b.min^{-1}$	0.61*	0.52	0.58*
No. of 10 min periods, HR>119 $b.min^{-1}$	0.67*	0.53	0.62*
No. of 20 min periods, HR>119 $b.min^{-1}$	0.75*	0.53	0.67*
No. of 5 min periods, HR>139 $b.min^{-1}$	0.80*	0.52	0.68*
No. of 10 min periods, HR>139 $b.min^{-1}$	0.71*	0.37	0.59*
No. of 20 min periods, HR>139 $b.min^{-1}$	0.55*	0.33	0.49*
No. of 5 min periods, HR>159 $b.min^{-1}$	0.24	0.57*	0.42*
No. of 10 min periods, HR>159 $b.min^{-1}$	0.14	0.46	0.29
No. of 20 min periods, HR>159 $b.min^{-1}$	0.15	-0.18	-0.01
No. of 5 min periods, HR>TOHR+20 $b.min^{-1}$	0.56*	0.58*	0.52*
No. of 10 min periods, HR>TOHR+20 $b.min^{-1}$	0.60*	0.59*	0.56*
No. of 20 min periods, HR>TOHR+20 $b.min^{-1}$	0.58*	0.60*	0.57*
No. of 5 min periods, HR>TOHR+30 $b.min^{-1}$	0.58*	0.61*	0.56*
No. of 10 min periods, HR>TOHR+30 $b.min^{-1}$	0.62*	0.62*	0.59*
No. of 20 min periods, HR>TOHR+30 $b.min^{-1}$	0.62*	0.62*	0.61*
No. of 5 min periods, HR>TOHR+50 $b.min^{-1}$	0.76*	0.65*	0.66*
No. of 10 min periods, HR>TOHR+50 $b.min^{-1}$	0.72*	0.59*	0.65*
No. of 20 min periods, HR>TOHR+50 $b.min^{-1}$	0.70*	0.48	0.60*
Total No. of heart rates, HR>TOHR+20 $b.min^{-1}$	0.42	0.44	0.36
Total No. of heart rates, HR>TOHR+30 $b.min^{-1}$	0.49	0.56*	0.46*
Total No. of heart rates, HR>TOHR+50 $b.min^{-1}$	0.61*	0.65*	0.57*
No. of 5 min periods, >125% TOHR	0.49	0.55*	0.46*
No. of 10 min periods, >125% TOHR	0.55*	0.44	0.42*
No. of 20 min periods, >125% TOHR	0.54*	0.62*	0.55*
No. of 5 min periods, >150% TOHR	0.56*	0.64*	0.54*
No. of 10 min periods, >150% TOHR	0.61*	0.65*	0.58*
No. of 20 min periods, >150% TOHR	0.62*	0.54*	0.54*
No. of 5 min periods, > 175% TOHR	0.63*	0.65*	0.59*
No. of 10 min periods,>175% TOHR	0.64*	0.57*	0.60*
No. of 20 min periods, >175% TOHR	0.61*	0.41	0.52*
Total No. of heart rates, HR>125% TOHR	0.37	0.45	0.33
Total No. of heart rate, HR>150% TOHR	0.43	0.63*	0.46*
Total No. of heart rates, HR>175% TOHR	0.50	0.68*	0.53*
No. of 5 min periods, >50% HRR	0.80*	0.52	0.64*
No. of 10 min periods, >50% HRR	0.70*	0.39	0.59*
No. of 20 min periods, >50% HRR	0.54	0.32	0.43*
No. of 5 min periods, >75% HRR	0.53	0.49	0.37*
No. of 10 min periods, >75% HRR	0.45	0.42	0.34
No. of 20 min periods, >75% HRR	0.0	0.0	0.0
Total No. of heart rates, >50% HRR	0.72*	0.64*	0.63*
Total No. of heart rates, >75% HRR	0.48	0.62*	0.48*

*Denotes significant correlation, $p<0.05$

Many of the heart rate activity indices showed moderate to good correlation with reported seven day activity time (Table 5.4). In general, the strength of the correlation improved as emphasis of the activity indices changed from light to moderate level thresholds (i.e. TOHR+50 gave better correlation than TOHR+30 which gave better correlation than TOHR+20) but did not improve with any increase in the duration of the monitoring period. Five, ten and twenty minute periods all yielded similar levels of correlation, particularly for the lower intensity measures (for example, the difference in correlation between using 5 minute bouts at TOHR+20 $b.min^{-1}$ and 20 minute bouts was only 0.04). At the most vigorous threshold levels (no. of HR>159 $b.min^{-1}$ and no.of HR>75% HRR), correlations tended to be poor. Referring back to table 3, the low correlations identified for many of the sustained vigorous activity indices were due to the extremely low number of children engaging in activity at these levels (in particular, not one child achieved a level of continuous intensity equivalent to a single 20 min periods with HR>75%HRR, correlation for this index with reported activity was consequently zero). Those measures yielding most consistent significant correlation for both males and females were those heart rate indices where activity was expressed relative to the baseline tickover heart rate.

Several of the heart rate activity indices which showed most significant correlation with reported seven day activity time were also examined using Spearman's rank correlation analysis. All measures showed close agreement in the ranking of the children from low to high levels of activity, as indicated by the observed moderate to good rank correlation with SDA (r=0.52 - 0.83) (Table 5.5).

Table 5.5: Spearmans rank correlation between selected activity indices and total seven day activity time.

	Males	Females	All
No. of 5 min periods, HR>139 $b.min^{-1}$	0.78*	0.52	0.65*
No. of 5 min periods, HR>TOHR+50	0.80*	0.62*	0.72*
No. of 5 min periods, HR>175%TOHR	0.61*	0.75*	0.71*
Total No. of heart rates, > 50% HRR	0.83*	0.61*	0.69*

* Denotes significant correlation, $p<0.05$

Table 5.6 shows mean activity scores by day for each of these selected measures. Repeated measures analysis of variance showed no significant difference between the means for any of the days ($p>0.05$ on all tests, not significant). The mean summary heart rate measures (mean HR, min HR and tickover HR) were particularly stable across the 7 days of measurement with the difference between mean daily scores being 4 $b.min^{-1}$ or less. Student's t-test analysis also showed no significant difference between the mean week day activity score and the mean weekend activity (for all summary heart rate measures and each of the selected heart rate activity indices, df=26, $p>0.05$). Spearman's rank correlation coefficient between mean week day activity score and mean weekend activity score ranged from 0.32 (No. of 5 min periods with heart rate >139 $b.min^{-1}$) to 0.70 (Total no. of heart rates >50% HRR).

Table 5.6: Mean activity scores by day.

	Day of Week						
	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Mean HR	95.8	97.4	97.1	99.8	96.2	97.0	97.8
Max HR	187.0	187.9	183.4	190.1	184.9	175.6	183.4
Min HR	63.0	64.5	62.1	62.5	62.7	63.2	61.3
Tickover HR	73.3	74.1	72.8	73.9	73.0	72.3	72.6
No. of 5 min periods, HR>139 $b.min^{-1}$	1.4	3.1	1.7	2.8	1.3	2.2	3.6
No of 5 min periods, HR>TOHR+50	4.7	6.5	5.9	8.6	4.4	7.5	9.4
No. of 5 min periods, HR>175%TOHR	2.8	5.6	4.8	6.9	3.1	6.3	8.0
Total No.of heart rates >50%HRR	25.6	37.6	34.8	45.1	26.3	33.6	39.9

Day to day variability of the heart rate activity indices was determined by intraclass correlation coefficient (Table 5.7). The baseline tickover measure, minimum daily HR and mean daily HR were most consistent across the 7 days of measurement (r=0.45-0.63). The transformed heart rate activity indices were less stable, despite no significant difference in the group means across days, individual heart rate activity was extremely variable from day to day and the intraclass correlation coefficent for each of the selected measures was low (R<0.10 to R=0.35). The children's diary reports also indicated considerable day to day variation in the activity levels of individuals (R=0.14, n=28). One child reported over 2 hours of activity on 2 days (due to rugby training and football on one day, a rugby match and football practice on the other) but on 2 other days he reported no moderate or vigorous activity. Many other children showed this pattern of active and sedentary days across the week of monitoring.

Table 5.7: Intraclass correlation coefficient for selected heart rate measures

	Males (n=14)	**Females (n=14)**	**All (n=28)**
Mean HR ($b.min^{-1}$)	0.53	0.34	0.45
Max HR ($b.min^{-1}$)	0.16	0.26	0.21
Min HR ($b.min^{-1}$)	0.52	0.57	0.54
Tickover HR ($b.min^{-1}$)	0.64	0.62	0.63
No. of 5 min periods, HR>139 $b.min^{-1}$	0.11	0.10	0.10
No of 5 min periods, HR>TOHR+50	0.23	0.28	0.25
No. of 5 min periods, HR>175%TOHR	0.29	0.34	0.31
Total No.of heart rates >50%HRR	0.27	0.41	0.35

A second approach to examining the effect of the measurement period (no. of days) on the activity score was to examine the actual error in the activity score when less than 7 days were included in the analysis. Table 5.8 shows the range of activity scores yielded when using just 1 to 6 days of heart rate data (score varies according to which combination of days are selected).

Table 5.8: Range of activity scores according to the number of days included in the analyses

	ACTIVITY INDEX No. of 5 min periods with HR>139b.min^{-1}						
Subject Number	No. of days included in analysis						
	1	2	3	4	5	6	7
1	0-10	0-12	0-13	0-13	1-13	3-13	13
2	1-10	3-14	7-19	11-23	15-27	20-29	30
3	0-7	1-14	4-21	11-28	18-31	25-32	32
4	0-3	0-5	1-6	2-7	3-8	5-8	8
5	0-6	0-10	0-13	2-15	5-15	9-15	15
6	0-8	0-16	1-21	2-22	7-23	15-23	23
7	0-10	0-17	4-23	9-28	15-32	22-32	32
8	0-29	0-41	0-44	1-45	4-45	16-45	45
9	0-13	0-26	2-31	4-33	9-34	22-35	35
10	0-8	0-10	0-12	1-13	3-13	5-13	13
11	0-2	0-3	0-3	0-3	0-3	1-3	3
12	0	0	0	0	0	0	0
13	0-3	0-4	0-4	0-4	0-4	1-4	4
14	0-12	0-16	0-20	0-20	4-20	8-20	20
15	0-12	0-13	0-13	0-13	0-13	1-13	13
16	0-16	0-29	0-35	1-36	7-36	20-36	36
17	0-2	0-2	0-2	0-2	0-2	0-2	2
18	0-6	0-11	1-13	3-15	5-16	10-16	16
19	0-4	0-5	0-5	0-5	0-5	1-5	5
20	0-17	0-27	1-30	2-31	5-32	15-32	32
21	0	0	0	0	0	0	0
22	0-1	0-1	0-1	0-1	0-1	0-1	1
23	0-5	0-7	0-9	0-9	2-9	4-9	9
24	0-3	0-5	0-5	0-5	0-5	2-5	5
25	0-12	2-22	4-28	7-31	13-33	23-35	35
26	0-4	0-7	1-9	2-10	4-11	7-11	11
27	0-3	0-4	0-4	0-4	0-4	1-4	4
28	0-2	0-3	0-4	1-5	2-5	3-5	5

For many children the activity index showed considerable variance from day to day, and when using less than 7 days, the activity score (in this case the number of 5 min periods with HR>139 $b.min^{-1}$) was highly dependent on whether active days or less active days were included in the analysis. Even when using 4 days of heart rate data, the activity score could be grossly underestimated. Taking each child's least active days, the range of error was 44-100% (excluding those who did no activity, n=2). For those children who were very sedentary, activity score was less affected by the number of measurement days (subject numbers, 12, 21 and 22). For those who were very active however, activity score was markedly altered depending which days were analysed. This was true for cases where children had consistent levels of activity each day (eg. subject number 2 & 3) or for cases where children had occasional very active days combined with inactive days (subject number 8, 9 and 20). Days when children participated in a school PE lesson or weekend sports game, had to be included in the analyses for that child's weekly level of activity to be given fair and accurate representation.

5.5 DISCUSSION

The selected sample showed good levels of aerobic fitness (as indicated by the mean shuttle run performance and predicted VO_2 peak scores). Mean predicted VO_2 peak scores (54 $ml.Kg.^{-1}min^{-1}$ for males, 46 $ml.Kg.^{-1}min^{-1}$ for females) are markedly higher than standards reported by Armstrong and colleagues (1991) for 11 to 16 year old children in England (Males: 49+/-6 $ml.Kg.^{-1}min^{-1}$; females, 41+/-6 $ml.Kg.^{-1}min^{-1}$) and are higher than normative records for this age group (Males: 50 $ml.Kg.^{-1}min^{-1}$, females, 44 $ml.Kg.^{-1}min^{-1}$, Shvartz & Reibold, 1990). The female group in particular showed high levels of fitness and contrary to current evidence (Armstrong et al 1994; NIFS, 1990; Currie & Todd, 1990) engaged in similar amounts of activity as the males. It is suspected that the sample used in the current study is biased towards fitter and more active children. A random selection procedure was not used. In order to evaluate heart rate variability across an entire week, children were selected on the basis of the quality of their heart rate data. The sample of 28 children (14 boys, 14 girls) were those children, from within a larger cohort of 122, for whom 6 to 7 days of uncorrupted data was obtained and who **also** provided a detailed diary account of their activities over that period. It is suspected that children who are very active and who hold more general interest in sports and activities may be more diligent in their reporting and are likely to provide a better return of data. Researchers relying on self report measures of activity should be alert to this tendency.

It was important that the sample provided a good spread of activity levels from low to high participation and this was clearly achieved as evidenced by the wide spectrum of activity levels reported (one child engaged in just 60 minutes of moderate to vigorous activity through the week compared with one who reported as much as 11 hours of activity). Overall, children reported participating in moderate to vigorous levels of activity for a mean time of 340 minutes per week, with both boys and girls engaging in similar mean levels. Heart rate activity indices also showed no significant difference between the sexes. It is difficult to make comparisons of these levels with other studies in view of the wide differences in methodological approach and analyses but the mean weekly activity time compares favourably against current recommendations for a minimum of 30 minutes moderate to vigorous activity per day (i.e. equivalent to 210 minutes per week or more) (Sallis & Patrick, 1994).

Contrary to current recommendations, activity levels in this group of children did not seem to be evenly spread throughout the week. Activity was extremely variable from day to day as indicated by the low intraclass correlation coefficients for each of the selected activity indices. Whilst this finding has been observed in other studies (NIFS, 1990), the implications of it have largely been overlooked. Most researchers continue to rely on heart rate activity data recorded from only a limited number of days (typically 3-4 days). Common practice is to use 2 to 3 weekdays and one weekend day (Livingstone et al, 1992; Armstrong et al, 1991, 1990) but even that procedure does not safeguard against missing important active periods from throughout the week. Given the evidence within the current investigation there is little to recommend recording heart rate for less than 6 days. It was shown that by restricting data measurement to fewer days, the outcome measure of weekly physical activity was often grossly underestimated. Table 5.7 illustrates how, even when using 4 days of data, as many as 13 of the 28 children could have been potentially classified as sedentary (zero activity bouts) depending on which days were observed. The heart rate data recorded over a full 7 days showed that only 2 children within the sample actually achieved this poor standard.

It is concluded that if children's activity is to be assessed for comparison against current recommendations, seven full days of heart rate measurement must be achieved. Recording data for fewer than 7 days may be appropriate if comparing mean activity levels between groups but cannot be used as a basis on which to judge the attainment of standards. Unfortunately, the recording of 7 days of heart rate data raises a considerable problem for researchers in terms of subject compliance. It has already been demonstrated that a large number of children dislike extended wear of the monitors and some may develop a skin reaction to the electrodes (Pilot study iv, Appendix II). Whilst it is obviously a standard to which researchers should aspire to, in most instances the recording of 7 days is likely to be extremely impractical. It is proposed that where a 7 day measure can not be achieved, special effort should be made to cover the unrecorded days by other means (e.g. activity diary). At least then the level of error can be evaluated and taken into full consideration.

The observed variability in heart rate is in close agreement with those of Gretebeck and Montoye, (1992) who reported that whilst mean heart rate showed a between day correlation of 0.62, when converted to a heart rate activity index, variability was considerably higher (R=0.44). Similarly, Mueller and colleagues, (1986) reported a Spearman's rank correlation of 0.73 - 0.85 for mean heart rate but only 0.29 - 0.33

when converted to an activity index (percentage of recording time with heart rate above specified level). Only Durant and coworkers (1992, 1993) report much lower between day variability (r=0.65-0.66) using a heart rate index of heart rates greater than 120 $b.min^{-1}$. This was further improved using a heart rate index expressed relative to resting heart rate (R=0.81, for percentage of heart rates greater than 125% RHR). Their research design was more limited in that that only two repeat days were actually examined. In addition, their study group included very young children (less than 7 years). Patterns of activity may be more consistent at this age where structuring of activity to specific days (PE, scouts, youth club activities, weekend sports and games) may be less pronounced.

In addition to assessing the number of days necessary to gain accurate reflection of children's activity levels, this study compared various heart rate activity indices on the basis of their correlation with reported moderate to vigorous activity. Preliminary analysis indicated that summary heart rate measures (mean daily heart rate, maximum daily heart rate and minimum daily heart rate) do not correlate well to activity level. This supports findings from previous researchers (Durant et al, 1993; Gretebeck & Montoye, 1992; Mueller et al, 1986). A better index of activity was achieved by expressing heart rate activity relative to a specified level of intensity and/or duration. Various methods of heart rate activity analysis were explored with many showing good correlation with the reported activity levels (r=0.33-0.80). The heart rate activity indices which showed best correlation with reported activity were gender specific. Activity in the male group was best identified by those indices which identified moderate to vigorous type activity (e.g. number of 5 and 10 min period with heart rate > 139 $b.min^{-1}$ and number of 5 and 10 min periods with heart rate >50% HRR). In females, the best correlates with activity were achieved using lower intensity activity indices (TOHR+20,30 and 50 $b.min^{-1}$, 125 and 150% TOHR) and total number of elevated heart rates rather than the number of sustained periods.

None of the heart rate activity indices emerged as a clear "winner" in terms of the ideal measure of physical activity. Clearly the recommended method of heart rate data analysis will depend on what precisely the researcher wants to assess. Using set cut off points such as >139 $b.min^{-1}$ and >159 $b.min^{-1}$ or using percentage of heart rate reserve examines relative high intensity exercise. Using tickover heart rate (or other baseline resting heart rate equivalent) plus 20,30, & 50 $b.min^{-1}$ or at a percentage level (125,150,175%) examines heart rate patterns at lower intensities. Whilst the latter appear to give a better index of activity in females, these indices are likely to be more susceptible to error. At low levels of activity, the relationship between heart rate and energy expenditure is weaker (Dauncey & James, 1979) and heart rate may be easily influenced by posture (Christensen et al, 1983), psychological stressors (Bateman et al, 1970) temperature and fatigue (LeBlanc, 1957). Based on both the correlation analysis and the reliability analyses conducted within this study, the most effective heart rate activity index for both sexes was achieved using 50% HRR. It is recommended however, that in order to allow for potential sex differences in the duration of activity, both the number of sustained active periods and the total number of heart rates above 50% HRR (irrespective of duration) should be assessed.

CHAPTER SIX

PHASE 3:

ASPECTS OF FITNESS AND PHYSICAL ACTIVITY IN EDINBURGH SCHOOL CHILDREN, AGED 13 TO 14 YEARS

6.1 INTRODUCTION

New physical activity guidelines for children have been devised (Sallis & Patrick, 1994) but very little is known about the extent to which Scottish children meet the recommended levels. Current evidence is largely based on findings from questionnaire surveys (Scottish Sports Council, 1993; Health Behaviours in Scottish Children, HBSC, Currie & Todd, 1990; Young Peoples Leisure & Lifestyles, Hendry et al, 1990) but whilst these can provide useful means of establishing trends in sports participation and popular modes of activity, they offer only a crude estimate of the more important aspects of health related physical activity, intensity, frequency and duration. Physical activity behaviors are known to be poorly reported by children, very few can give an accurate account of past activity and self report measures often reflect the cognitive abilities of the children rather than give any real reflection of physical activity levels (Lamb & Brodie, 1990; Forth & Salomi, 1988; Baranowski et al, 1984). In view of this, methods which combine self report measures with some means of objective assessment (activity monitors, doubly labelled water or heart rate monitors) are generally recommended (Saris, 1985).

Continuous heart rate monitoring is one of the most popular field methods for the assessment of physical activity in children and has received increased usage over the past decade (Sallis et al, 1993; Livingstone et al, 1992, Janz et al, 1992; Armstrong et al, 1991, 1990; Riddoch et al, 1991b; Verchuur & Kemper, 1985). It has been used to examine physical activity patterns of adolescent groups in England (Armstrong et al, 1994, 1991, 1990) and Northern Ireland (Atkins et al, 1995; Livingstone et al, 1992, Riddoch et al, 1991b), but Scottish studies, to date, have been limited. Heart rate monitoring has been used to assess energy expenditure in very young children in Edinburgh (Payne et al, 1995) but not with older groups. As current evidence indicates that the decline in children's activity levels appears to start in adolescence (Amsterdam Growth Study, 1995; Northern Ireland Fitness Survey, 1989), it is perhaps the activity patterns of secondary age children that requires most urgent examination.

The recommendations laid down by Sallis and Patrick (1994) specify the following;

(1) That every child should be physically active daily, or nearly every day, as part of play, games, sports, transportation, recreation, physical education, or planned exercise in the context of family, school and community activities.

(2) Adolescents should engage in 3 or more sessions per week of activities that last 20 mins or more at a time and that require moderate to vigorous levels of exertion.

Precisely what intensity is indicated by "moderate to vigorous" activity is somewhat ambiguous. Sallis and Patrick (1994) qualify it broadly as any activity "which requires as much effort as brisk or fast walking". Whilst heart rate monitoring studies generally base their analyses around this principle, inconsistencies remain regarding the selection of heart rate cut off points to indicate moderate and vigorous activity. Durant and colleagues (1993, 1992) used a cut off of 120 $b.min^{-1}$ to indicate moderate level activity in young children (3-7 years). In older children, 140 $b.min^{-1}$ is often used (Armstrong et al, 1991, 1990; Sallis et al, 1993) but a recent review of heart rate monitoring studies suggests that the 140 $b.min^{-1}$ level may be more equivalent to vigorous (rather than moderate) level activity (Pate et al, 1994). Other indices include heart rate activity relative to 50% VO_2 peak (Livingstone et al, 1992; Riddoch et al, 1991b; Verchuur & Kemper, 1985), and heart rate relative to a percentage of heart rate reserve (Atkins et al, 1995; Janz et al, 1992). Whilst the various techniques are related (for example, Riddoch and colleagues (1991) report that for most children, aged between 11 and 16 years, 50% VO_2 peak is roughly equivalent to 142 $b.min^{-1}$), the measures are not directly comparable and will detect subtlely different levels of activity. Other popular field methods, such as questionnaire surveys, are also inconsistent. Questionnaires typically describe moderate activity as any activity which "gets you warm and slightly out of breath" and vigorous activity as that which "makes you sweat and gets you out of breath" (HEA, 1995; ADNFS, 1992; Currie & Todd, 1990; NIFS, 1989). These descriptors however are open to extremely subjective interpretation and respondents often tend to report the total duration of exercise sessions rather than the length of time for which they are actually active (NIFS, 1989; Sunnegarde et al, 1985).

A review of large population-based studies in United States (CDC, 1992; NYFS, Ross & Gilbert, 1985) estimates that nearly all children in the United States (>80%) meet the first of the activity guidelines (Pate et al, 1994). They also estimate that approximately two thirds of males and half of females meet guideline 2, participating in moderate to vigorous activity of 20 minutes duration at least 3 times a week. Whilst levels in Britain are unclear, similar findings have been indicated by the Allied Dunbar National Fitness Survey (1992) where two thirds of males and half of females, 16 to 24 years (the youngest of the age groups studied) reported participating in 12 or more moderate to vigorous exercise sessions during the preceding month. This estimate may be rather high given that the response rate for the interview survey was only 75% and that whilst this is a good response for this type of survey, the final sample is likely to be biased toward more active individuals. Levels of activity within Scottish groups or young adolescent groups was not considered. Indeed, very little information pertaining to the activity patterns of Scottish adolescents is currently available. Results from the only national survey in Scotland suggest that many children (11 to 15 years) engage in limited levels of physical activity outwith school physical education (40% reported exercising once a week or less frequently) but these findings are based on just two broad questions within a larger health related survey and need further clarification (Health Behaviours Scottish School Children, HBSC, Currie & Todd, 1990). Whilst over half the children studied reported exercising 4 to 7 times per week outside of school, these findings, founded purely on the basis of self report, must be viewed with caution. A difference of up to 67% between the estimates of activity levels derived from questionnaire surveys compared with results from small group studies using heart rate monitoring has been noted (Pate et al, 1994)

The aim of the current study was to conduct a descriptive survey of aerobic fitness and physical activity patterns in Edinburgh school children, aged 13 to 14 years. The survey was conducted through selected schools in the region, using field based measures; principally, the self report activity diary (Durnin & Passmore, 1967), continuous heart rate monitoring and the 20 m shuttle run test (Leger et al, 1988). A review of these techniques was conducted previously (Chapters 4 & 5) and each has been shown to provide practical and valid means for the assessment of physical activity and aerobic fitness levels in children. The following issues were examined:-

(i) Is there a sex difference in the levels of aerobic fitness of Edinburgh children?

(ii) Is there a sex difference in the levels of physical activity (in terms of intensity, frequency and duration of activity) over 1 week of monitoring?

(iii) How many children meet the current recommendations for physical activity as laid down by Sallis and Patrick (1994)?

6.2 METHOD

(a) Subjects

The sample was selected from groups of children, aged 13 to 14 years attending three state and four[11] independent schools in Edinburgh. One hundred and twenty two children were selected from the state and independent groups and matched across each of the 3 academic terms, spring, summer and autumn. Samples were selected as PE class groups (as opposed to random sampling from the whole year group) and therefore sample size varied slightly according to school policy on class grouping. None of the school classes were streamed according to academic or athletic ability and it is assumed that the selected classes provided a reasonable cross-sectional sample of children of that age group and school.

[11] The odd number of selected schools was due to 2 single sex schools (1 male, 1 female) being included in the independent sample. It is not the intention of this research investigation to conduct a comparison of single sex verses coeducational schooling systems. However, given that 52% of independent schools in Scotland are single sex (SCIS/ISIS Directory, 94/95), it was deemed appropriate that these groups should be represented.

Most PE groups contained 30 to 40 pupils from which a sample of 10 boys and 10 girls (from each school) were randomly selected to take part in the heart rate monitoring. After selection, 2 pupils indicated that they would be unsuitable for inclusion (one was a competitive swimmer, training on a daily basis and requested to withdraw, the other was intending to be away over the weekend period). Two other children were randomly selected from the remaining group to replace them.

(b) General Procedures

Ethical approval was granted by Lothian Health Board Pediatric Ethics Committees and Lothian Education Authority gave formal permission to approach schools in the Edinburgh area. Independent schools out with local authority control were contacted directly via the head teacher. All schools were supplied with a letter of introduction and an information booklet detailing the measures to be recorded and the test procedures (See Appendix I). On approval from the head teachers, the sample classes were randomly selected from the 2nd or 3rd year group and a letter of information and information booklet sent to all PE departments, parents and individuals concerned.

Participants performed 2 shuttle run tests, each test performed on separate occasions, set one to three weeks apart. The intervening (or following) week was used for the recording of height, weight and body composition measures. Following completion of all other measures, children were divided into sets of 7-10 pupils and heart rate monitored over a period of 1 week. The general pattern of data collection, along with details of the equipment used, is indicated in Table 6.1.

Table 6.1 Test Order and Equipment: PHASE 3

WEEK	TEST	EQUIPMENT	MANUFACTURERS
1	Shuttle Test 1	Shuttle Test Battery	National Coaching Foundation, Leeds
2	Shuttle Test 2	ditto	ditto
3	Height Weight Skinfold Thickness	Portable Stadiometer Scales Harpenden Skinfold Calipers	Child Growth Foundation, London Seca, Germany Holtain, Germany
4	Physical activity(Group a, n=10)	PE 4000 Heart rate monitors Activity Diary	Polar Electro, Finland
5	Physical activity(Group b, n=10)	PE4000 Heart rate monitors Activity Diary	Polar Electro, Finland

<u>(c) Anthropometric Measures</u>

Skinfold thickness measures were recorded at 2 body sites (triceps and subscapular) according to the techniques described by Lohman and colleagues (1991). Full details of the equipment and procedures are provided previously (Phase 1; Chapter 4). All measures were conducted on the school premises, usually in the school changing rooms or quiet room where privacy of the subjects could be assured. In general, children were taken in groups of 2/3 from their regular PE class and returned back to that class once measurements had been completed. In two of the schools, the regular tester was aided by a member of the PE staff who recorded the height and weight measurements. These assistants were briefed on the procedures prior to commencement of the data collection. All skinfold thickness measures were recorded by the same trained observer.

(d) Shuttle Run Test

Procedures for the shuttle run test were similar to those adopted during Phase 1 (Chapter 4) except that heart rate monitors were not worn and no measurement of peak heart rate was taken. Shuttle run tests were carried out in the school gymnasiums and/or games halls (sprung wooden/synthetic flooring) with 8 to 20 subjects tested at any one time. Whenever test groups exceeded 10 subjects, the regular tester was aided by a trained assistant who helped with the administration of the test, motivation of the group and recording of the results. Peak performance was recorded in terms of maximal shuttle run speed and by the total number of 20m laps completed. Peak oxygen uptake ($ml.Kg^{-1}min^{-1}$) was estimated using prediction equations developed specifically for children aged 13/14 years (Chapter 4, Phase 1).

(e) Heart Rate Monitoring and Activity Diaries

Twelve heart rate monitors (Polar Electro, Finland, PE4000) were available for use. Each school group was sub divided into sets of seven to ten pupils and data recorded from each set over two/three separate weeks. Care was taken to avoid having pupils from the same class wearing the monitors at the same time, thus limiting the chance of data interference through close proximity of the transmitters. The monitors were set to record heart rate on a minute by minute basis and were worn for a period of one week.

Over the same period, children were issued with a seven day activity diary; a small pocket sized booklet, in which they were asked to record details their activity throughout each day of monitoring. Type of activity (e.g. tennis, football, eating, sleeping) along with details of the duration of activities (estimated where possible to the nearest minute) and intensity of activity (stroll/walk/fast walk; jog/run/sprint) were to be detailed.

All children were visited on a daily, or twice daily, basis to ensure that instructions were being adhered to and that the monitors were functioning properly. Heart rate data was downloaded to a portable computer, the memory space on the monitors cleared, and heart rate recording recommenced as soon as possible. Activity diaries were also reviewed with each child and checked to ensure that no important periods of activity had been forgotten from the previous day. If any blanks appeared on the activity diaries children were reminded of likely opportunities for activity from the previous day, (for example, preschool activities, any PE activities, school breaks and any evening activities), and asked to think back to what they were doing during those times. These meetings were held during school registration or the school lunch recess period depending on the school's request.

(f) Data analysis

Descriptive statistics (age, height, weight, skinfold thicknesses, shuttle run performance, predicted VO_2 Peak) were determined and differences between sexes assessed by the students t-test. Differences between the means were accepted as significant at the $P<0.05$ level.

Initial assessment of activity levels was based on the 7 day diary reports. All activity equivalent to a brisk walk or above, and sustained for 5 minutes or longer, was totalled for each day for each child. Total weekday and total weekend activity time, total school based and non school based activity time, and total seven day activity time (SDA, minutes) were determined. School based activity was defined as any physical activity organised by the school or taking place during school hours (i.e. it included school recreation activity as well as curricular PE classes and also included after school training and Saturday matches if played as part of a school team).

Heart rate activity was examined using 2 methods selected from Phase 2; (i) by the number of 5, 10 and 20 minute periods with heart rate above 119, 139 and 159 beats per minute (Sallis et al, 1993; Armstrong et al, 1991, 1990), (ii), by the number of 5, 10 and 20 minute periods with heart rate above 50% of heart rate reserve and the total number of heart rates greater than 50% heart rate reserve. Heart rate reserve was determined as the difference between maximum heart rate (220-age) and baseline heart rate (tickover heart rate, TOHR, $b.min^{-1}$, the lowest 15 minute moving average from each day of recording). For all activity indices, differences between males and females were determined by the Mann Whitney U test for non-parametric data. Relationships between the activity measures and shuttle run performance, predicted peak oxygen uptake and skinfold thickness measures were examined using Pearson's product moment correlation.

6.3 RESULTS

6.3.1 Shuttle run performance and predicted VO_2 Peak.

Physical characteristics, shuttle run performance and predicted VO_2 peak of the children are shown in Table 6.2. Results are reported for 91 children (44 boys, 47 girls). It was deemed preferable to restrict the sample size in favour of maintaining the quality of the data and from the original sample of 122 children, 31 children were screened out due to insufficient activity data (refer to the next section, 6.3.2, p192)

Table 6.2: Descriptive statistics (mean +/- sd) by gender

	Male (n=44)		Female (n=47)	All (n=91)
AGE (years)	13.8 (0.4)		13.9 (0.5)	13.8 (0.4)
HEIGHT (cm)	159.5 (9.9)		160.4 (7.0)	160.0 (8.5)
WEIGHT (Kg)	50.3 (9.3)		53.5 (7.6)	51.9 (8.6)
Sum of Skinfolds (mm)$	18.7 (8.6)	*	25.4 (6.7)	22.1 (8.3)
SHUTTLE RUN (No. of laps)	70.8 (20.1)	*	49.3 (17.5)	59.5 (21.6)
SHUTTLE RUN (Max.shuttle speed, $km.h^{-1}$)	12.2 (1.0)	*	11.1 (0.9)	11.6 (1.1)
PREDICTED VO_2 PEAK ($ml.Kg^{-1}min^{-1}$)	53.6 (6.6)	*	45.5 (7.1)	49.4 (7.9)

* Denotes significant difference between males and females

$ Sum of triceps and subscapular skinfolds

No sex differences were observed for mean age, height or weight, but boys were significantly leaner ($t=-4.1$, $df=88$, $p<0.05$), ran for longer on the shuttle run test (no. of laps, $t=5.4$, $df=88$, $p<0.05$; maximal shuttle speed, $t=5.4$, $df=88$, $p<0.05$) and had higher predicted VO_2 peak ($t=5.6$, $df=87$, $p<0.05$).

6.3.2 Activity levels

(a) Seven day activity diary

Total seven day activity[12] (SDA), total weekday and weekend activity, and total school based and non school based activity were examined. Reported activity time in minutes is shown in table 6.3.

Table 6.3 Self reported activity time, mins+/- (sd).

	Males (n=44)		Females (n=47)	All (n=91)
Total seven day activity (SDA, mins)	239 (162.0)		194 (139.2)	211 (154.0)
Total weekday activity	185 (125.2)		147 (93.8)	165 (111.2)
Total weekend activity	54 (72.3)		48 (67.7)	51 (69.7)
Total school based activities	137 (111.8)		126 (83.5)	131 (97.8)
Total out of school activities	102 (122.9)		68.3 (103.1)	85 (113.7)
No. of active days in week	3.3 (1.6)		3.2 (1.5)	3.2 (1.6)

[12] The quality of the data return was more variable than that achieved for Phase 2. Whilst some children gave detailed minute by minute accounts of their activity, others were inclined to report memorable blocks of activity (e.g a 40 minute gymnastics class) without detailed breakdown of fluctuations of intensity of activity within that session. This presented a number of methodological problems, in particular, the process of simply totalling reported activity time presented a bias towards those children who were less thorough in their reporting. To avoid penalising those children who did provide a detailed breakdown of activity (ie who indicated that a 40 minute PE lesson involved 5 minutes changing at either end, 10 minutes instruction and only 20 minutes of actual play), all communal PE and games sessions were counted as a standard time block (as indicated in school curriculum timetable) and this standard activity duration applied to all children who participated in that class. It is accepted that this procedure is likely to overestimate time spent in moderate to vigorous activity but it provides a more standardised measure and enables better comparison between individuals. Whilst objective record of duration was available for all school PE and games lessons, home based and weekend activities were less easy to screen for accuracy. In these cases, individual reports of activity duration were accepted as written.

Each child's total seven day activity time (SDA, mins) was thus determined by the duration of any school PE or games lessons in which they participated (typically 40-90 minutes), plus the total number of 5 minutes bouts of moderate to vigorous activity (equivalent to a brisk walk or above) reported out with curricular activity.

Children showed wide variation in total weekly time spent in moderate to vigorous activity (range 40 mins to 11 hours). A mean SDA of 221 minutes was recorded (average 30 minutes per day) but this was not spread evenly throughout the week. Most children interspersed very active days with inactive days and reported a mean frequency of participation in moderate to vigorous activity of 3 days per week (range 1 to 7 days). Forty four percent reported being active on 4 days in the week or more, whilst 12% were active on just one day. On average, boys reported being slightly more active than girls, spending approximately 45 mins per week longer in moderate to vigorous activity (a difference of 23%) but this was not statistically significant. Most activity took place during weekdays rather than at weekends but when expressed relative to the number of days, time spent in moderate to vigorous activity on weekdays and weekends days was similar (33 mins and 25 mins per day respectively). Most activity was school based (61%) rather than out of school (39%). with boys engaging in more out of school activities than the girls (approximately 30 minutes longer).

<u>(b) Screening of heart rate data</u>

Prior to analysis, all heart rate data was screened for erroneous values. For all values >210 (suspected cause: - electrical interference by external device) and values<50 (suspected cause: - faulty transmission from transmitter to the microcomputer watch) data values on either side of the artifact were averaged to the nearest whole number. This procedure was carried out for periods of missing data of 1 to 5 minutes duration. For periods of missing data of longer duration (>6 minutes) erroneous values were simply substituted by a standard 100 $b.min^{-1}$. The value of 100 $b.min^{-1}$ was regarded as being low enough not to be falsely identified as an active period whilst high enough not to influence any studies of resting heart rate levels (Figure 6.1 & 6.2). Data files in which the erroneous data constituted over 8% of the total daily recording were not accepted as reliable representation of the days activity and were subsequently withdrawn.

All heart rate data recordings were carefully checked against the activity diaries to ensure that the monitors had not been removed during any periods of important activity. In 6 cases, children went swimming and the monitors were unable to record heart rate due to excessive interference in the water. Four girls and two boys had one hour of swimming activity which has not been accounted for in the heart rate analysis. The other major period when activity was not recorded was when children competed in "important" sports competitions. Thirteen children (all male) expressed concern about wearing the monitors during inter-school games (rugby, n=6; football, n=5; squash, n=1, and athletics, n=1). In these cases, monitors were removed just prior to the game. The time period during which the watch was removed and the activity engaged in over that period was carefully noted in the activity diaries. Where appropriate, averaged data from other children, or averaged data from the subjects own files recorded during training games, was substituted into the missing sections of the data files (See figures 6.3 & 6.4).

Fig 6.1 Sample Heart Rate Data Trace (Missing data during inactive period)

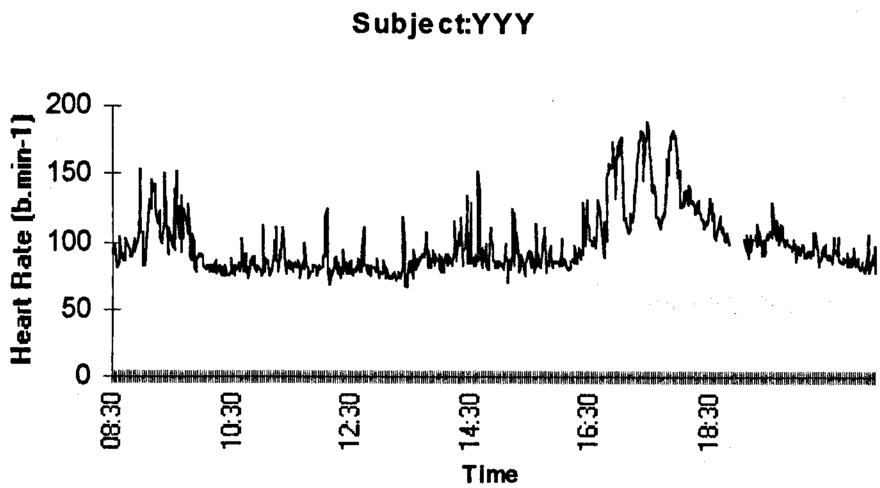


Fig 6.2 Same Heart Rate Data Trace (Missing Data accounted for using a standard 100b.min^{-1} to cover the unrecorded period)

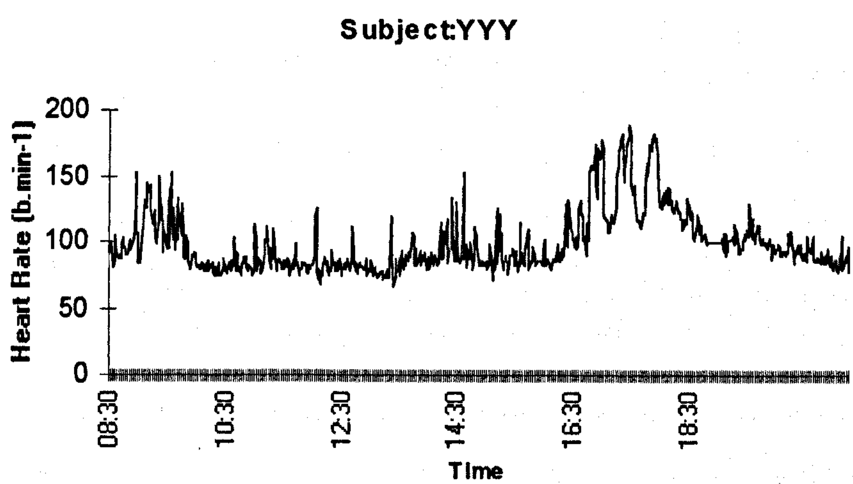


Fig. 6.3 Sample heart rate data trace (missing data during active period - as indicated by activity diary)

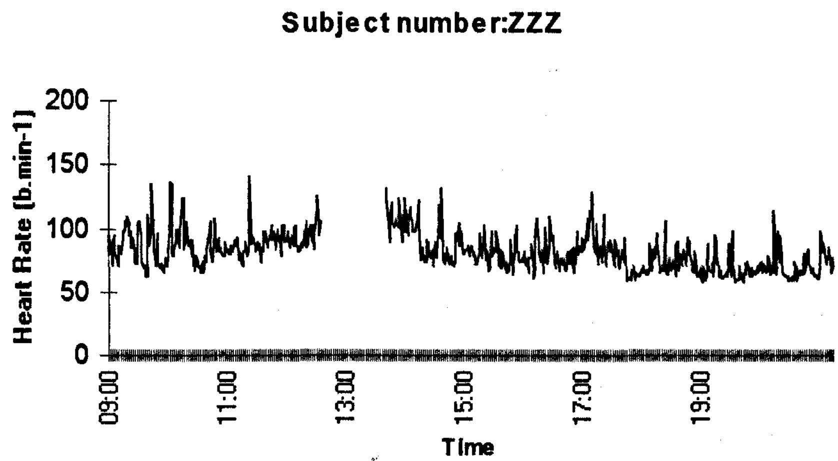
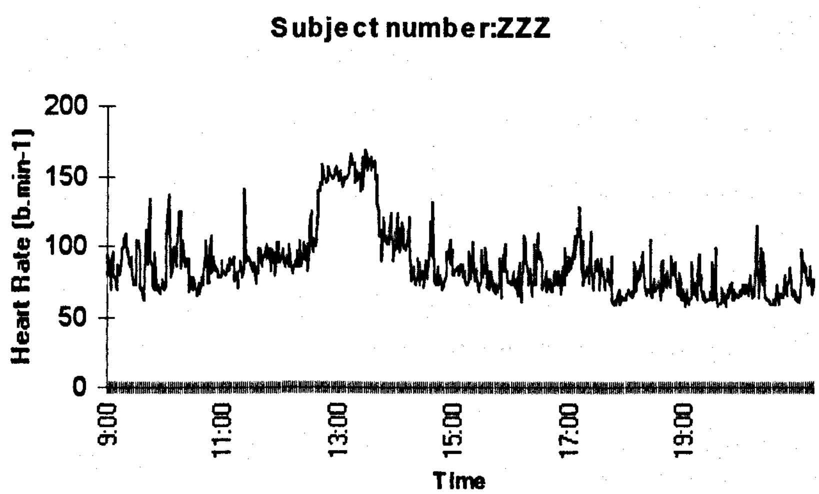


Fig. 6.4 Same heart rate data trace (missing data accounted for by using averaged data from other subjects).



From a sample of 122 children originally selected for the heart rate monitoring study, data for 4 full days or more was obtained for 91 of the children (75%) (see table 6.4). As is evidenced by the substantial volume of data obtained, most children enjoyed wearing the monitors and were quick and responsive to pick up and carry out the required procedures for data collection. Duration of daily recordings ranged from 540 to 989 minutes. The total missing data for the group of 91 children constituted 141 days out of the targeted 637 (91 x 7 days), indicating a 78% success rate in data recording. Children were only included in the final sample provided that the supporting activity diary information indicated that all known periods of significant moderate to vigorous activity had been accounted for (apart from the swimming activity mentioned previously).

Table 6.4: No of Days recordings attained.

No of Recording Days Attained	No.of Children
*0-3	31
4	17
5	28
6	34
7	12
Total	122

* Excluded from analysis due to insufficient data

(c) Heart rate data analysis

Summary statistics for each of the selected heart rate indices are shown in Table 6.5 overleaf. A significant difference between males and females was found for the number of 5, 10 and 20 minute periods greater than 139 $b.min^{-1}$ (Mann-Whitney U test, corrected for ties, z=2.1; z=2.6 and z=2.1 respectively, p<0.05). None of the other variables showed significant sex differences.

Table 6.5: Summary heart rate statistics (mean +/- sd)

	Males		Females	All
TOTAL WEEKLY ACTIVITY				
No. of 5 min periods HR>119 $b.min^{-1}$	62 (39.9)		51 (31.3)	56.6 (35.9)
No. of 10 min periods HR>119 $b.min^{-1}$	24 (23.3)		16 (11.4)	19.6 (18.5)
No. of 20 min periods HR>119 $b.min^{-1}$	8 (9.4)		4 (4.2)	5.8 (7.3)
Total no. of elevated HR>119 $b.min^{-1}$	596 (253.4)		589 (227.4)	592 (239.0)
No. of 5 min periods HR>139 $b.min^{-1}$	19 (15.4)	*	12 (11.5)	15.6 (13.9)
No. of 10 min periods HR>139 $b.min^{-1}$	6 (6.7)	*	3 (3.6)	5 (5.6)
No. of 20min periods HR>139 $b.min^{-1}$	2 (2.8)	*	1 (1.3)	1 (2.3)
Total no. of elevated HR>139 $b.min^{-1}$	231 (122.4)		207 (105.9)	219 (114.1)
No. of 5 min periods HR>159 $b.min^{-1}$	4 (5.0)		3 (4.1)	3 (4.6)
No. of 10 min periods HR>159 $b.min^{-1}$	1 (1.6)		0 (0.7)	1 (1.2)
No. of 20 min periods HR>159 $b.min^{-1}$	0 (0.4)		0 (0.2)	0 (0.3)
Total no. of elevated HR>159 $b.min^{-1}$	83 (54.0)		74 (47.0)	78 (50.2))
No. of 5 min periods HR>50%HRR	14 (12.0)		11 (11.9)	12.4 (12.0)
No. of 10 min periods HR>50% HRR	4 (5.2)		3 (3.8)	4 (4.6)
No. of 20 min periods HR>50% HRR	1 (2.1)		1 (1.3)	1 (1.8)
Total no. of heart rates > 50% HRR	193 (112.9)		188 (124)	190 (117.9)
WEEKDAY/WEEKEND ACTIVITY[$]				
Total no. of heart rates >50% HRR (weekdays)	145 (89.5)		132(76.4	138 (82.8)
Total no. of heart rates >50% HRR (weekends)	49 (59.1)		57 (70.3)	53 (64.9)
No. of 5 min periods HR>50%HRR (weekdays)	9 (9.1)		6 (6.7)	7 (8.0)
No. of 5 min periods HR>50%HRR (weekends)	5 (7.9)		4 (6.0)	4 (7.0)
No. of 10 min periods HR>50% HRR (weekdays)	3 (3.9)		1 (2.0)	2 (3.1)
No. of 10 min periods HR>50% HRR (weekends)	2 (3.5)		1 (2.2)	1 (2.9)

[$] Analysis for %HRR only. Other indices yielded similar relative levels of weekend and weekday activity.

Total weekly participation in moderate to vigorous activity (number of elevated heart rates greater than 119 $b.min^{-1}$) was 596 for males and 589 minutes for females (equivalent to 85 min per day). If restricted to elevated heart rates (>119 b.min^{-1}) which were sustained for 5 mins or longer, weekly time spent in moderate to vigorous activity was lower, 310 minutes for the boys and 255 minutes for the girls, (45 mins and 36 mins per day respectively). As with the activity diary reports, more activity was performed during the week than at the weekends but when expressed relative to the number of days, levels were similar.

The heart rate data generally did not show normal distribution and given the high standard deviations noted in Table 6.5, mean heart rate levels may be somewhat misleading. Data was thus examined further in relation to the percentage of children attaining the specified levels of heart rate intensity and duration. Results are shown in Tables 6.6 to 6.8 below.

Table 6.6: Percent of subjects and number of sustained periods with heart rate above 119 b.min^{-1} (over one week of monitoring).

	BOYS(n=44)	GIRLS (n=47)
5-min periods		
0	0.0	0.0
1	0.0	0.0
2	0.0	0.0
3 or more	100.0	100.0
10-min periods		
0	0.0	4.3
1	0.0	2.1
2	0.0	2.1
3 or more	100.0	91.5
20-min periods		
0	18.2	10.6
1	9.1	25.5
2	4.5	12.8
3 or more	68.2	51.1

Table 6.7: Percent of subjects and No. of sustained periods with heart rate above 139 b.min^{-1} (over one week of monitoring).

	BOYS(n=44)	GIRLS (n=47)
5-min periods		
0	2.3	8.5
1	4.5	4.3
2	2.3	8.5
3 or more	90.9	78.7
10-min periods		
0	20.5	27.7
1	15.9	17.0
2	2.3	12.8
3 or more	61.4	42.5
20-min periods		
0	47.7	70.2
1	13.6	17.0
2	4.5	6.4
3 or more	31.1	6.4

Table 6.8: Percent of subjects and No. of sustained periods with heart rate above 159 b.min^{-1} (over one week of monitoring).

	BOYS (n=44)	GIRLS (n=47)
5-min periods		
0	29.5	46.8
1	18.2	10.6
2	4.5	8.5
3 or more	47.7	34.1
10-min periods		
0	61.4	76.6
1	13.6	14.9
2	11.4	6.4
3 or more	13.6	2.1
20-min periods		
0	88.6	95.7
1	9.1	4.3
2	2.3	0.0
3 or more	0.0	0.0

Boys were more active than girls at all levels of intensity (moderate, >119 $b.min^{-1}$, vigorous, >139 $b.min^{-1}$ and very vigorous, 159 $b.min^{-1}$) with differences (0-25%) being most marked at the >139 $b.min^{-1}$level. Most children (91% of the boys and 79% of the girls) engaged in 3 or more 5 minute periods with heart rate greater than 139 $b.min^{-1}$. Only 2.3% of the boys and 8.5 % of the girls failed to achieve a single 5 minute period with heart rate greater than 139 $b.min^{-1}$ over the monitoring period. Participation in active periods of longer duration was less. Almost a quarter of both males and females did not attain a single 10 minute period with heart rate above 139 $b.min^{-1}$. Those that did however engage in 10 minute periods of that intensity tended to achieve 3 or more during the week (Boys, 61.4% and Girls, 42.5%). Participation in 20 minute periods with heart rate > 139 $b.min^{-1}$ was much higher for boys than for girls. (Boys, 31.1%; Girls, 6.4%). It is interesting to note that boys tended to be highly active (over 30% engaged in 3 or more 20 minute periods with heart rate greater than 139 $b.min^{-1}$) or did not participate in any prolonged periods of activity (48% failed to achieve a single 20 minute period during the week of testing). Very few fell within the middle ground (1 or 2 periods of 20 minute duration, heart rate greater than 139 $b.min^{-1}$) presenting a U-shaped distribution (Figure 6.5). For girls the number of children participating in 20 minute sustained bouts of activity declined with the number of active periods identified. The number of sustained periods of highly vigorous activity (HR>159 $b.min^{-1}$) was low for both sexes (Figure 6.6).

Figure 6.5: Percentage of children and number of 20 min periods attained over one week of testing (Heart rate>139b.min^{-1}).

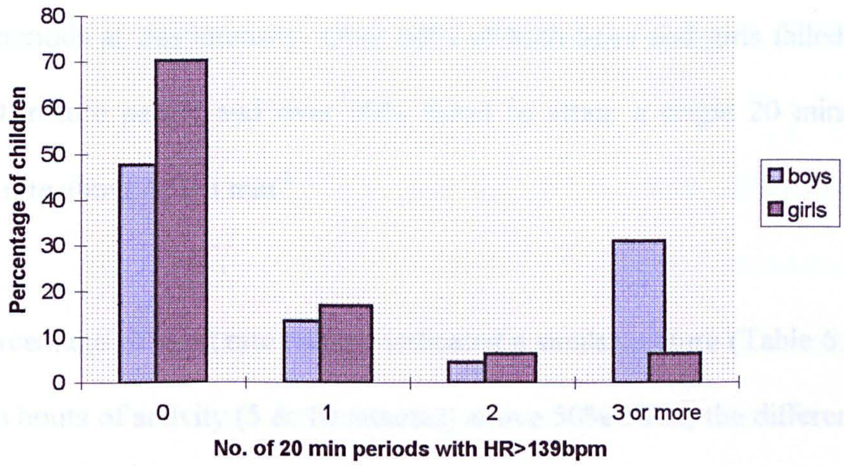
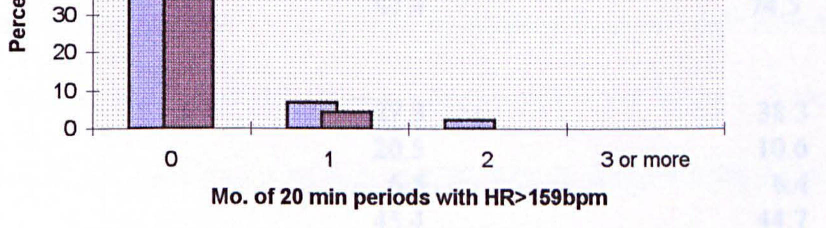


Figure 6.6: Percentage of children and number of 20 min periods attained over one week of testing (Heart rate > 159 b.min^{-1}).



Participation in more vigorous periods of activity (heart rate >159 $b.min^{-1}$) was lower in both males and females. Most children attained at least one 5 minute period with heart rate greater than 159 $b.min^{-1}$ (Boys, 70.5%; Girls, 53.2%) but few engaged in more prolonged periods at this intensity. Over 60% of both boys and girls failed to attain a single 10 minute period and over 90% failed to attain a single 20 minute period with heart rate above 159 $b.min^{-1}$.

Analysis using percentage of heart rate reserve indicated a similar picture (Table 6.9). For short duration bouts of activity (5 & 10 minutes) above 50% HRR, the difference between male and female participation rates was at most 12%. The percentage of males and females attaining 3 or more sustained 20 minute periods however was more disparate (Males 27%; Females 2%).

Table 6.9: Percent of subjects and No. of sustained periods with heart rate above 50%HRR (over one week of monitoring).

	BOYS(n=44)	GIRLS (n=47)
5-min periods		
0	6.8	10.6
1	6.8	6.4
2	0.0	8.5
3 or more	87.4	74.5
10-min periods		
0	27.3	38.3
1	20.5	10.6
2	6.8	6.4
3 or more	45.4	44.7
20-min periods		
0	59.1	68.1
1	6.8	19.1
2	6.8	10.6
3 or more	27.3	2.1

Accepting moderate activity as any activity where heart rate was elevated above 119 $b.min^{-1}$, all heart rate activity levels were examined in relation to the exercise recommendations laid down by Sallis and Patrick (1994). When examined according to the total elevated heart rates (>119 $b.min^{-1}$) **all** children apart from one achieved guideline 1(30 mins of activity per day on all or most days, i.e. a minimum of 210 minutes per week) with a mean level of 85 mins per day identifed. If examined according to sustained bouts of activity (HR>119 $b.min^{-1}$, minimum 5 mins duration), 68% of boys and 53% of girls attained the recommended volume of activity. It was noted however that regardless of which analytical criteria were adopted, the frequency was less than 6 days per week (mean 3.2 +/-1.6 days per week). For Guideline 2, sustained periods of moderate to vigorous activity, (at least 3 twenty minutes periods over 1 week), the target level was achieved by 68% of males and 51% of females.

(d) Quality of physical activity

Heart rate data indicated that the quality of specific activity sessions (intensity and duration) varied markedly between individuals. Team sports such as football, rugby, and hockey showed reasonably consistent levels of intensity between individuals but other reported activities showed wide variation (See Table 6.10 below). Football, which was played during school breaks as well as after school, ranged from 10 to 140 minutes duration. During play, mean heart rate for one boy was as high as 164 $b.min^{-1}$ (indicating a highly vigorous game) whilst, for another it was just 123 $b.min^{-1}$ (moderate level activity). Similarly, for boys engaged in the same game of cricket, the intensity of activity varied widely between individuals and depended on whether they played as bowlers, batsmen or fielders. Greatest variation was indicated for activity described as 'dance/exercises' which many of the girls did in the evenings at home. Sessions between varied from 10 to 90 minutes with a mean heart rate range of 111 to 160 $b.min^{-1}$. Heart rates were rarely sustained for long periods (<5 minutes) at a vigorous level during these activities. One girl who claimed 90 minutes of dance/exercises actually only attained a total of 15 minutes with heart rate sustained above 139 $b.min^{-1}$. Typical patterns of heart rate activity are given in Figures 6.7- 6.14.

Table 6.10 Mean heart rate (+/-sd) & duration during common sports/activities

Sport/Activity	No. of children included in the analysis	Mean heart rate, $b.min^{-1}$ (+/- sd)	Range of activity duration (mins)
Football	15	147 (18.7)	8-140
Rugby	5	165 (17.3)	45-90
Hockey	5	138 (24.5)	40-95
Cricket	9	116 (20.6)	60-120
Table Tennis	6	127 (17.7)	20-90
Gymnastics	7	128 (19.2)	30-90
Dance/Exercises	9	119 (30.8)	10-90
Cycling (paper round)	8	122 (17.0)	30-90

Fig: 6.7 Typical heart rate pattern during a game of FOOTBALL

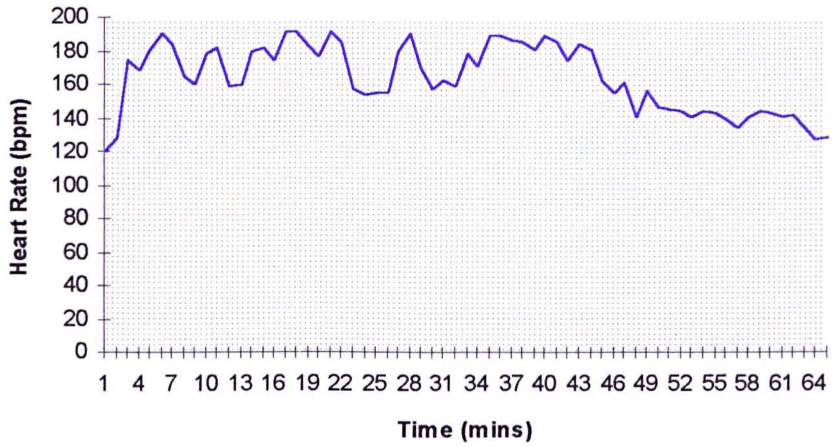


Fig: 6.8 Typical pattern of heart rate activity during a game of RUGBY

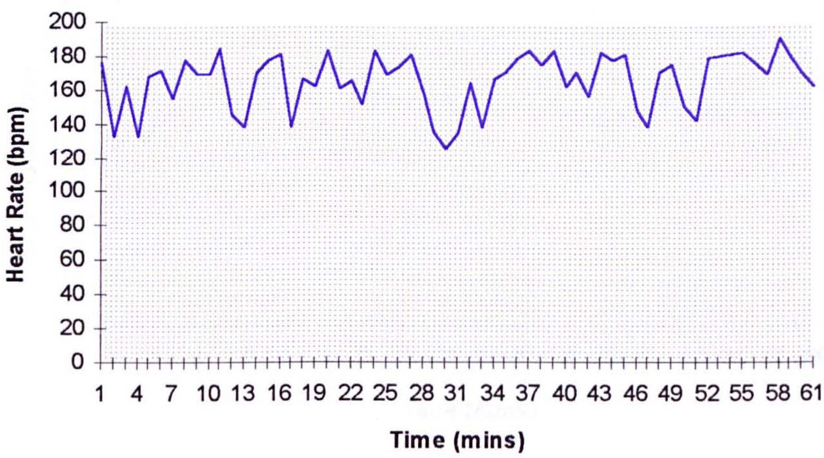


Fig 6.9: Typical pattern of heart rate activity during a game of HOCKEY

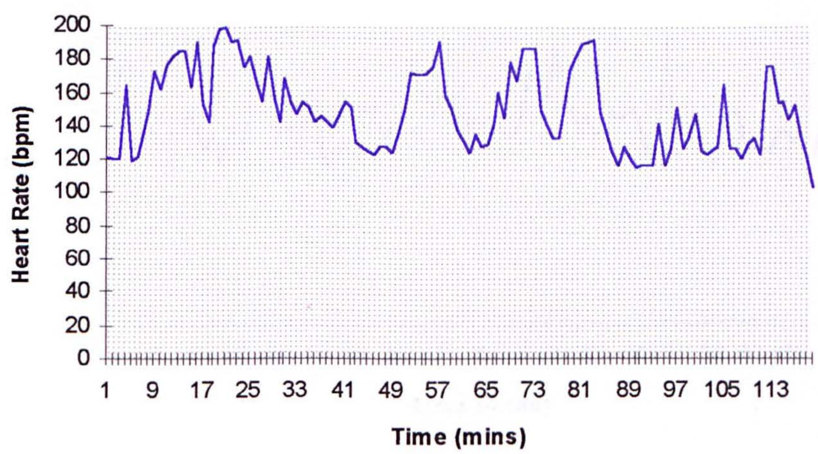


Fig 6.10 Typical heart rate activity patterns: CRICKET PLAYERS.

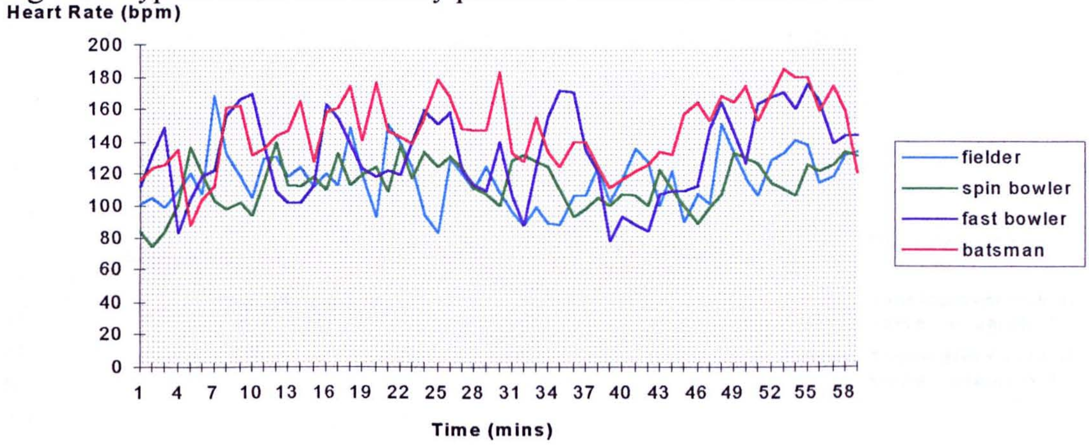


Fig 6.11 Typical pattern of heart rate activity :TABLE TENNIS

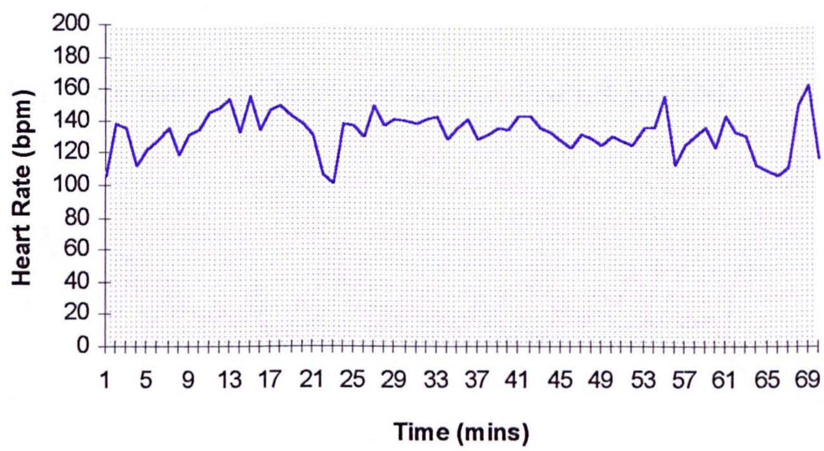


Fig 6.12 Typical pattern of heart rate activity during GYMNASTICS

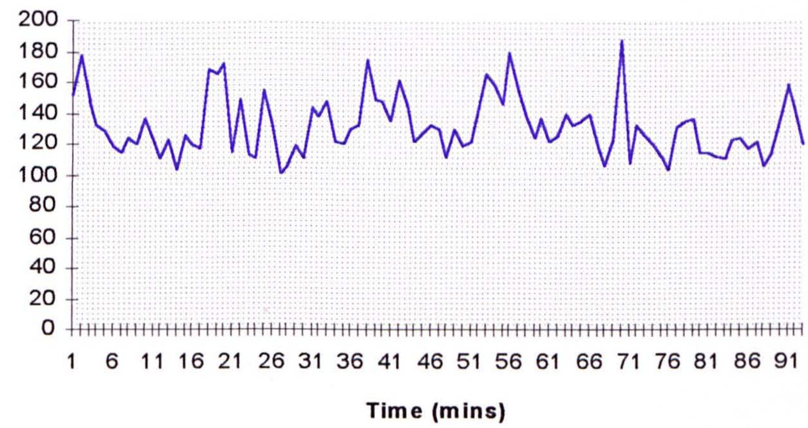


Fig 6.13 Typical patterns of heart rate activity: DANCE/EXERCISES

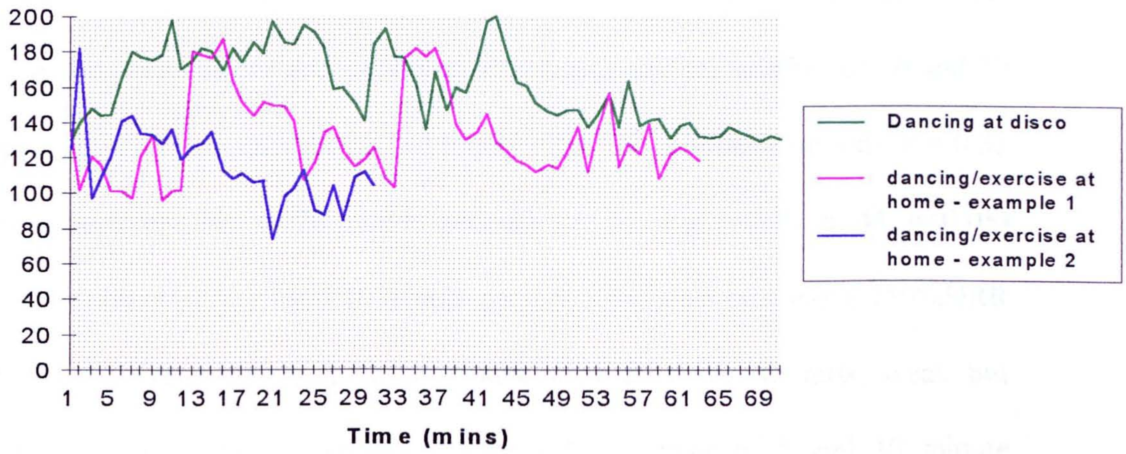
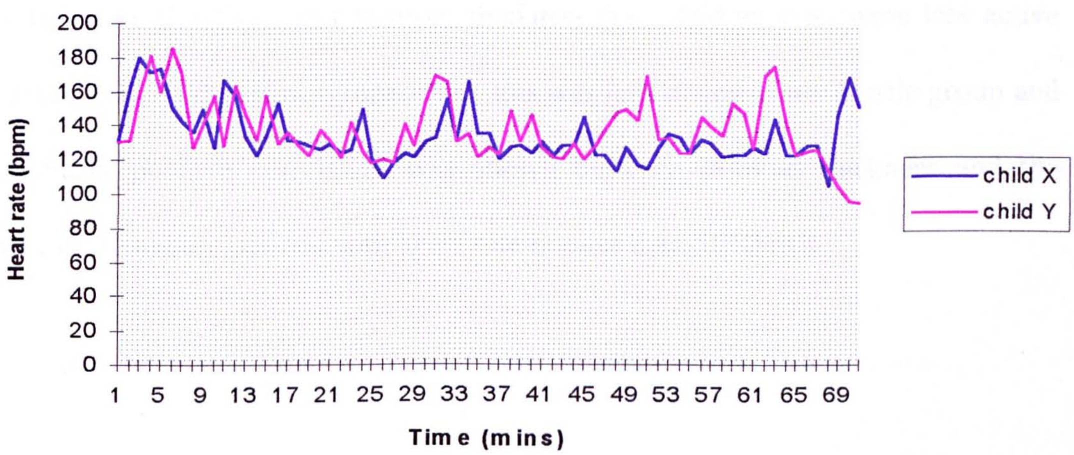


Fig 6.14: Typical pattern of heart rate activity: PAPER ROUND



(e) Correlation between fitness and physical activity measures

In boys, a weak but significant correlation was identified between both aerobic fitness indices (Shuttle performance and predicted VO_2 Peak) and the number of 10 and 20 minute period with heart rate above 139 $b.min^{-1}$ (No. of 10 minute periods, $r = 0.33$ and 0.36 respectively; No. of 20 minute periods, $r=0.37$, and $r=0.39$, $n=44$, $p<0.05$) and with the number of 5, 10 and 20 minute periods with heart rate above 150%HRR (0.38, 0.39, 0.39 respectively, $p<0.05$) (Table 6.11 & 6.12). In girls, weak but significant correlations were identified between the number of 5 and 10 minute periods with heart rate above 159 $b.min^{-1}$ and shuttle run performance ($r = 0.35$ and $r = 0.31$ respectively, $n=47$, $p<0.05$). Whilst males showed the expected negative trend between physical activity and skinfold thickness (i.e. children who were less active had greater skinfold thickness measures), this was less strong in the female group and a significant positive correlation was shown between skinfold thickness and the number of 20 minute periods with heart rate greater than 50%HRR.

Table 6.11: Pearsons product moment correlation between selected fitness and physical activity indices: Males

	Predicted VO_2 peak $ml.kg^{-1}.min^{-1}$	Shuttle run, no. of laps	Max. shuttle speed, $km.h^{-1}$	Sum of 2 skinfolds (mm)
No of 5 min periods, HR>119b.min^{-1}	-0.09	-0.07	-0.05	-0.06
No of 10min periods, HR>119b.min^{-1}	0.10	0.04	0.07	-0.12
No of 20 min periods, HR>119b.min^{-1}	0.19	0.13	0.16	-0.19
No of 5 min periods, HR>139b.min^{-1}	0.29	0.24	0.27	-0.26
No of 10 min periods, HR>139b.min^{-1}	0.36*	0.33*	0.36*	-0.29
No of 20 min periods, HR>139b.min^{-1}	0.39*	0.37*	0.40*	-0.29
No of 5 min periods, HR>159b.min^{-1}	0.26	0.21	0.23	-0.26
No of 10 min periods, HR>159b.min^{-1}	0.30	0.26	0.27	-0.26
No of 20 min periods, HR>159b.min^{-1}	0.23	0.20	0.23	-0.17
No of 5 min periods, >50%HRR	0.38*	0.38*	0.41*	-0.26
No of 10 min periods, >50%HRR	0.39*	0.42*	0.44*	-0.24
No of 20 min periods, >50% HRR	0.39*	0.43*	0.44*	-0.24
Total no of heart rates >50% HRR	0.25	0.25	0.27	-0.18

* Denotes significant correlation, $p<0.05$

Table 6.12: Pearsons product moment correlation between selected fitness and physical activity indices: Females

	Predicted VO_2 peak $ml.kg^{-1}.min^{-1}$	Shuttle run, no. of laps	Max. shuttle speed, $km.h^{-1}$	Sum of 2 skinfolds, (mm)
No of 5 min periods, HR>119b.min^{-1}	-0.02	0.10	0.03	0.09
No of 10min periods, HR>119b.min^{-1}	0.02	0.12	0.05	0.06
No of 20 min periods, HR>119b.min^{-1}	0.05	0.16	0.08	0.05
No of 5 min periods, HR>139b.min^{-1}	0.07	0.21	0.13	0.11
No of 10 min periods, HR>139b.min^{-1}	0.00	0.15	0.08	0.18
No of 20 min periods, HR>139b.min^{-1}	-0.08	0.05	0.00	0.27
No of 5 min periods, HR>159b.min^{-1}	0.23	0.35*	0.29*	-0.02
No of 10 min periods, HR>159b.min^{-1}	0.22	0.31*	0.27	-0.04
No of 20 min periods, HR>159b.min^{-1}	0.18	0.18	0.20	-0.05
No of 5 min periods, >50%HRR	0.01	0.17	0.10	0.21
No of 10 min periods, >50%HRR	-0.05	0.12	0.06	0.28
No of 20 min periods, >50% HRR	-0.11	0.05	0.00	0.32*
Total no of heart rates >50% HRR	0.00	0.11	0.10	0.28

*Denotes significant correlation, $p<0.05$

6.4 DISCUSSION

(a) Aspects of Physical Fitness

Mean height, weight and skinfold thickness measures were in close agreement with other studies of 13 to 14 year old children (Pyke, 1986; Kemper, 1989, 1986; NIFS, 1989; Armstrong et al, 1990). Overall mean shuttle run performance and predicted peak oxygen uptake were also similar to reported levels (Armstrong et al, 1990, 1988; NIFS, 1989; Leger et al, 1988). The mean predicted peak oxygen uptake of 53.6 $ml.Kg.^{-1}min^{-1}$ for males and 45.5 $ml.Kg.^{-1}min^{-1}$ for girls is less than that reported for children in the Netherlands (AGS, 1995; Kemper et al, 1989) but compares favorably against normative data for adolescent children (Shvartz & Reibold, 1990) and other British studies (Armstrong et al, 1991,1990).

The earliest records of VO_2 peak in children are from an American study conducted during the late 1930's (Robinson, 1938) which identified a mean VO_2 peak of 47.1 $ml.Kg.^{-1}min^{-1}$ for 14 year old boys (range 36.4 to 55.4 $ml.Kg.^{-1}min^{-1}$). The higher levels of mean VO_2 peak shown for the current Scottish group supports claims that there is little evidence for a decline in children's fitness levels (Armstrong et al, 1989). In fact, compared to earlier records of Scottish children in Strathclyde (Watkins et al, 1983, Farrally et al, 1980), standards are considerably improved (16% difference, based on Tuxworth's translation of physical work capacity (PWC170) measures to VO_2 peak, (1988)). The Scottish studies may not be directly comparable given that the early studies assessed PWC170 rather than VO_2 peak but the considerable margin of difference gives reasons for optimism in regard to children's current levels of aerobic power. Regional differences in aerobic power may also be apparent but this cannot be confirmed or excluded without further investigation.

A 17% difference in relative aerobic power between males and females was observed. This again has been reported previously (Krahenbuhl et al, 1985), where a comprehensive review of peak oxygen uptake measures in children indicates a difference of 1.5% at age 6 which may increase to over 30% at age 16. Much of this difference is due to the greater accumulation of subcutaneous body fat in females, which increases overall body mass and is metabolically less active. Sex differences in haemoglobin levels in the blood are also acknowledged. In adults, haemoglobin concentrations are 158 $g.l^{-1}$ and 139 $g.l^{-1}$ for males and females respectively (Astrand & Rodahl, 1986) but levels for children are less well established. Six year old children have similar haemoglobin levels regardless of sex (Braden & Strong, 1989; Godfrey et al, 1971), and Shephard (1971) found no significant difference in levels for 14 year old children (mean Hb, 141 $g.l^{-1}$ for males and females). However, at some point along the adolescent years, levels for males and females start to diverge and lower blood concentration of haemoglobin in females will contribute to reduced capacity for aerobic metabolism.

(b) Physical activity (measurement techniques)

Whereas previous studies have relied on a research technician/trained staff to set up and operate the monitors for each of the subjects (Gretebeck & Montoye, 1992; Durant et al, 1993, 1992; Armstrong et al, 1991, 1990), this study looked at the opportunity for allowing children themselves to act as research helpers, placing and operating the monitors themselves. With this procedure, monitoring was potentially able to proceed from the moment the child rose from bed to when they returned to bed in the evening. Whilst in practice most children required a break from wearing the monitors and did not wear them for the full duration of waking hours, it still enabled the monitoring period to be selected specifically around active periods and thus minimised the potential for missing important periods of early morning activity (eg. paper round) or late evening activity (eg disco dancing). Had a strict 12 hour, 8:30am to 8:30pm, protocol been adopted, as is typical of previous studies, (Armstrong et al, 1991, 1990) these active periods would have been missed.

Most children enjoyed wearing the monitors, were quick to follow the test procedures and were able to operate the monitors efficiently. Seventy five percent of children returned heart rate data covering 4 days or more. Most studies using heart rate monitors in children have only achieved a maximum of 4 days (Payne et al, 1995; Sallis et al, 1993; Livingstone et al, 1992; Riddoch et al, 1991b; Armstrong et al, 1991, 1990). Missing data for the 91 children who achieved 4 days or more amounted to 22%. Comparison of this rate of data return with other studies is restricted by the fact that very few researchers have actually attempted to quantify or report the extent of data loss. Gretebeck and Montoye (1992) report a 2% data loss in their study of heart rate patterns in adults. Most studies however have indicated much greater levels. Livingstone and colleagues (1992) mention "detachment of electrodes and/or fiddling with the receiver controls" resulting in data loss and, from a sample of 36 children only half the subjects completed 3 days of recording. Verchuur and Kemper (1985), reported that almost 40% of the average 24 hour heart rate scores could not be calculated due to unreliable recordings. Similar levels (35% unrecorded days) were also reported by Riddoch and colleagues for children in Northern Ireland (1991b). As preventative measures, Armstrong and co-workers (1989) covered the monitor control buttons to prevent tampering by inquisitive subjects and Sallis and colleagues (1993) secured the transmitters firmly to the chest using tape and elastic bandage. Neither studies however report on the success of these procedures nor document the percentage of data loss. In general, the methods of heart rate data collection employed in this current study appear to be effective, and maintained a high level of data return. Furthermore the heart rate data was backed up by the self report 7 day diaries providing an extremely detailed picture of mode, frequency, duration and intensity of activity across an entire week. Whilst the level of detail given on the activity diaries varied between individuals, with some reporting minute by minute activity and others just recording the main active periods, daily meetings with the children enabled thorough review of previous day activities and helped to ensure that all major periods of activity were accounted for.

(c) Physical activity levels

Boys engaged in more activity than the girls at all levels of intensity and duration, but differences were only statistically significant for periods of activity above 139 $b.min^{-1}$. Sex differences in participation, particularly at the more vigorous levels of exertion have been reported by studies of adolescents from throughout Europe (Livingstone et al, 1992; Riddoch et al, 1991b; Armstrong et al, 1991, 1990; NIFS, 1989; Fuchs et al, 1988; Sunnegarde et al, 1986; Telama et al, 1985) and America (YRBS, 1992; Ross & Gilbert, 1985). Boys and girls appear to have similar activity levels up to puberty (Verchuur & Kemper, 1985) but levels for both sexes decline throughout the adolescent years with boys being more active at all ages (NIFS, 1989; Malina, 1990, 1986).

It was noted that when total activity levels were examined (i.e. total number of elevated heart rates irrespective of duration) activity levels for males and females were more equivalent (Total heart rates >119 $b.min^{-1}$ was 596 and 589 mins/week for males and females respectively; total heart rates > 50% heart rate reserve was 193 & 188 mins/week respectively). This suggests that whilst adolescent boys and girls may engage in similar absolute levels of activity, the patterns of activity (how it is spread throughout the day) may be very different. Girls appear to engage in shorter, more frequent bouts of sporadic activity (typically <5 mins duration) whilst boys engage in more vigorous, longer duration activity. Other studies which have assessed activity according to total elevated heart rates rather than sustained periods of heart rate have also indicated no significant sex differences at moderate levels of activity (Janz et al, 1992; Riddoch et al, 1991b). It is only when sustained periods of more vigorous level activity is examined that sex differences in activity appear to emerge (Armstrong et al, 1991, 1990).

The levels reported for the current study (approximately 45 mins per day moderate to vigorous activity for males and 36 mins per day for girls) are considerably lower than reported activity levels from questionnaire surveys where over 2 hours of moderate to vigorous activity per day have been quoted for males and over one hour per day for females (FVFS, 1993; Aaron et al, 1993; NCYFS, 1985; Sunnegarde et al, 1985).

Questionnaire surveys however, are known to be particularly susceptible to exaggeration of subject activity (Pate et al, 1994), with children tending to overestimate their self reported activity. The figures for the current study, having been derived from a more objective measure of activity, are likely to provide a more realistic estimate of activity levels and do not necessarily indicate poorer levels for the Scottish group. Comparison with previous studies which have used heart rate monitoring techniques show closer agreement (Table 6.13).

Table 6.13: Heart rate monitoring studies for children 11-16 years: reported time spent in moderate to vigorous activity (mins/day).

Researchers	Age (yrs)	Measure & Criteria	Activity Level (mins/day)	
			Males	Females
Verchuur & Kemper, (1985)	12-14	HR> 50% VO_2 peak	78	60-72
Riddoch et al, (1991b)	11-16	HR>50% VO_2 peak	24	17
Livingstone et al,(1992)	12-15	HR> 50% VO_2 peak	52	15
Janz et al, (1992)	6-17	Total HR>60%HRR Prepubescent Pubescent Post pubescent	 24 11 2	 29 8 8
Armstrong et al, (1990)	11-16	HR> 139 $b.min^{-1}$ Weekdays:- Weekends:-	 45 42	 33 19
Sallis et al (1993)	11-16	HR> 119 $b.min^{-1}$ HR> 139 $b.min^{-1}$	63-114 23-35	43-106 11-30
This study	13-14	Total HR>119 $b.min^{-1}$ Total HR>139 $b.min^{-1}$ HR>119 $b.min^{-1}$, sustained for 5 mins or longer Total HR>50% HRR Weekdays:- Weekends:-	85 33 45 28 29 25	84 30 36 27 26 29

As can be seen from Table 6.13, activity levels for children in the current study were at the lower end of the reported range for heart rate monitoring studies. It should be noted however that the methods employed by the various studies have not been consistent and therefore values are not directly comparable. The heart rate index of 50% VO_2 peak is roughly equivalent to the 139 $b.min^{-1}$ cut off but examines heart rate activity at a slightly higher threshold (Livingstone et al, 1992; Riddoch et al, 1991b). In the current study, mean daily activity time was determined according to the number of sustained periods (minimum of 5 minutes duration) with heart rate above 119 $b.min^{-1}$ and 139 $b.min^{-1}$. This procedure is likely to yield lower estimates than studies which have used total heart rate recordings including all isolated elevated heart rates. When Armstrong and co-workers (1991, 1990) analysed their data according to the number of sustained periods, reported levels were actually lower than for the Scottish group. A higher percentage of boys and girls from the current study engaged in 3 or more 5 minute periods with heart rate greater than 139 $b.min^{-1}$ (This study: boys, 91%, girls, 79%; Armstrong et al, 1991: boys 68%, girls, 54%). Similarly, for more sustained periods of 20 minutes duration, 31% of boys and 6% of girls achieved 3 or more bouts, compared with 5% and 3% respectively reported in the English study. As before, these results must be weighed up with respect to the methodological differences between the studies. Armstrong and colleagues (1991) used heart rate data from 3 days of monitoring and may therefore have missed some important periods of weekly activity. The observed difference is thus most likely to be due to the more rigorous assessment procedures incorporated within the current study and on the weight of the evidence there are no real differences in the actual activity levels of the Scottish and English groups.

In terms of the current physical activity recommendations (Sallis & Patrick, 1994), findings indicate that nearly all children achieved the recommended volume of moderate activity (>210 mins per week) if assessed according to the total elevated heart rate levels (HR<119 b.min^{-1}). Less children engaged in sustained bouts of activity (5 mins duration or longer) at this intensity (68% boys, 53% girls) and frequency of activity was below standard with few achieving 30 minutes daily or nearly every day. b.min^{-1}). Rather than spreading activity evenly throughout the week, most children tended to be very active on some days and very inactive on others. Whilst 44% exercised on 4 or more days in the week (including school based activity), this level is lower that reported in the Health Behaviours Scottish Children Survey where over half the children claimed that they exercised outside of school 4 -7 times a week (Currie & Todd, 1990). The HBSC survey also found that males were more likely to take free time exercise, estimated as up to 4 or more hours per week. This sex difference was observed in the current study but the time spent in free time activity was much less, amounting to a difference of just 30 minutes per week between the sexes.

The second recommendation (at least 3, 20 minute sustained periods of moderate to vigorous activity) was again attained by approximately 70% of boys and 50% of girls. This is closely comparable to the findings of the Youth Risk Behaviour Study (YRBS, 1992) which estimated that 38-70% of adolescents participate in moderate to vigorous sessions 3 or more times a week (62-70% males, 38-51% females) and data from the Allied Dunbar Fitness Survey of young adults, (16-24 years) where two thirds of males and half of females reported participating in 12 or more moderate to vigorous exercise sessions during the preceding month. Only a Canada based survey has reported higher levels of participation (74% males, 67% females; age 15 to 19 years) (Stephens, 1993). Given that each of these surveys is based on data from questionnaires the figures quoted are likely to be overestimates. In general, however the evidence is in agreement with the current findings and suggests that levels of activity for the Scottish group are comparable to other Western nations.

Other aspects of the physical activity measures showed some disparity from previous research findings. In particular, research in the US has indicated that most activity in the adolescent population occurs outside of school (Ross & Dotson, 1985). This was not the case in the current study, with children spending up to 60 minutes longer in school based activity compared with non school based activity. Curricular school activity constituted the only activity for many of the children studied (45%). The Northern Ireland Fitness Survey found that 30% of boys and girls took no exercise outside of that provided by the school. The exceptionally high levels observed within the current Scottish group is likely due to the nature of the research sample. The sample was split evenly between state and independent schools, with all schools in the latter group providing an extensive games programme (both voluntary and compulsory) to supplement the weekly PE lessons. Figures for school based activity may also have been boosted by the inclusion of school recreation activities and school games. The tremendous importance of physical education in providing opportunity for physical activity is however highlighted and schools clearly have a major role in boosting physical activity participation.

Parcel and colleagues (1987) examined intensity of activity during school based activities and found that for some children the actual volume of aerobic activity may be very limited. During a typical school PE lesson, they identified that 32.8% of the time was spent in class organisation and management, 27.5% playing sports and games, 13.5% in skill practice, 11.4% in non-aerobic fitness activities, 8.6% in instruction and only 6.1% of the total lesson time was actually spent in aerobic activities. If this is common to most schools, (and it is likely given that the principle aim of physical education is skill development and that fitness training is secondary to this (Sharp, 1990)), then it becomes increasing important for children to engage in regular out of school activities in addition to their school PE. School recreation and early evening recreation may be particularly important. In this study, it was observed that boys took part in more out of school activities than girls (mean time, 102 minutes per week versus 68 minutes per week) and that boys tended to be more active during school breaks. Whilst many girls did engage in activity in the evenings after school, this unsupervised, non school based activity showed highly variable levels of exercise intensity and duration. Many girls reported taking part in home-based exercises/dance but for some there was considerable mismatch between the activity duration reported in the activity diaries and the actual time identified by the heart rate data (i.e. whilst they reported being "active", they were actually not exerting themselves to any great extent and heart levels remained low, <119 b.min^{-1} for most of the session). Whilst it is encouraging that children are obviously seeking to engage in physical activity in their own time, in many cases these activity bouts were of poor quality and were unlikely to be of benefit to cardiovascular health.

This observation flags up the inherent problem of relying on self report data alone to estimate time spent in physical activity. When some reported activity bouts actually involve only limited levels of physical exertion it is of tremendous benefit to be able to back up the self report data with a more objective measure of exercise intensity. Recommendation for using a combination of heart rate measurement techniques is supported (Saris, 1985). When used in conjunction with an activity diary, continuous heart rate monitoring clearly provides detailed information on intensity, frequency, duration and mode of activity and in addition the two methods provide a cross check for each other. Erroneous reading on the heart rate monitors will be made obvious by the diary information whilst the actual intensity of activity bouts reported within the diary can be made clear.

Correlations between the heart rate activity measures, shuttle run performance and predicted VO_2 peak were modest (significant range, 0.31-0.44) but were higher than those identified by Pate and colleagues (1990) for 8 to 9 year old children (r=0.17-0.33) and for adults (r=0.13-0.19, Eaton et al, 1995). In Morrow and Freedson's review of research investigations into the physical activity/physical fitness relationship in children, the reported correlations were typically 0.16-0.17 (1994). It remains unclear whether the failure to establish a clear relationship between aerobic fitness and activity levels in children is due to the lack of any real relationship between the two variables or whether it is simply a weakness in the measurement tool. The evidence for a stronger correlation shown by the current study may be part due to the improved methods of activity measurement used (recording activity over a full 7 day period, ensuring activity undertaken in the early mornings and late evenings was included, checking activity diaries to ensure all important periods of activity were accounted for).

In summary, results from this study indicate that standards of fitness and physical activity for Edinburgh school children are reasonable compared with other countries. It is encouraging that the majority of children are active and that many, especially boys are very active (31% of boys engaged in 3 or more 20 minute periods of vigorous activity over the week of monitoring). Nevertheless, an estimated 30% of boys and 50% of girls did not achieve the current recommended levels for moderate to vigorous physical activity. Two percent of boys and 9% of girls failed to engage in a single 5 minute period with heart rate greater than 139 $b.min^{-1}$ and a further 21% of boys and 28% of girls failed to engage in a single 10 minute period with heart rate elevated above 139 $b.min^{-1}$. There was a noted tendency, particularly for the boys, for children to be either very active or very inactive, suggesting that focus should be placed upon encouraging the most sedentary groups to engage in more regular bouts of moderate level activity. It is worrying that most children were not making regular physical activity part of **daily** routine. There is a need to encourage greater participation in after school activities, particularly for girls, and to encourage more activity to be undertaken on a daily basis.

CHAPTER SEVEN

GENERAL DISCUSSION & CONCLUSIONS

A three phase investigation was undertaken to examine aspects of aerobic fitness and physical activity patterns in Edinburgh school children. The following sections provide a summary of each phase and discuss the main conclusions and wider implications of the research findings.

7.1 PHASE 1: The reliability and validity of the 20 metre shuttle run test as a predictor of peak oxygen uptake in Edinburgh school children, aged 13-14 yrs.

7.1.1 Research summary

This study enabled careful evaluation of the twenty metre shuttle run test and it's application as a field test for the assessment of peak oxygen uptake in children. Peak oxygen uptake, shuttle run performance and anthropometric measures were examined in a group of Edinburgh school children (n=33), aged 13 to 14 years. Reliability of all the measures was determined by calculating the intraclass correlation coefficient of reliability for each variable measured across three separate test days. This was followed by exploratory multiple regression analyses to assess the validity of the 20m shuttle run test as a predictor of peak oxygen uptake in children. New prediction equations for estimating peak oxygen uptake from shuttle run performance were developed. Cross validation using a second sample of children (n=24), also aged 13 to 14 years, showed the new equations to have good predictive power across a wide range of aerobic performance (root mean square error of prediction, 4.35 $ml.Kg^{-1}min^{-1}$, 9.2%).

Overall, the 20 metre shuttle run test was shown to be a practical test of aerobic performance being easy to administer, requiring no sophisticated equipment, and readily performed by children within their curricular PE session. Set up time was minimal (approximately 10 minutes) and it was possible to test up to 20 children within scheduled class time (typically 40-45 minutes). Schools were thus very amenable to the conduction of the tests and participation rates were high. The advantages of the test in terms of practical application in the field are probably unrivalled by any other predictive test of aerobic fitness. It's inherent simplicity and the ability to test several subjects at the same time make it ideal for large scale surveys. The test's capacity to predict peak oxygen uptake is not absolute but the observed correlation between the two measures was high ($r=0.64$ to 0.79) and it yielded good estimates of peak oxygen uptake for both male and female groups.

All anthropometric measures (height, weight, and skinfold thickness measures at the biceps, triceps, subscapular, and suprailiac sites) were extremely consistent over the 3 days of testing ($R>0.94$). The tests of aerobic power (shuttle run test and treadmill test of peak oxygen uptake) showed lower levels of reliability ($R=0.79$ and 0.89 respectively), the latter being improved by the use of strict definitional criteria (maximum heart rate, respiratory quotient, subjective signs of fatigue) to establish whether maximal limits have been attained (BASS, 1988). These criterion measures are widely adopted as standard procedure for laboratory determination of peak oxygen uptake but are less feasible to implement within field based measures. The recording of physiological measures, such as heart rate, blood lactate, and/or oxygen uptake during the shuttle run test is impractical and would detract from the test's simplicity. This is particularly true if the test continues to be used in schools as part of the physical education programme.

On the basis of the current findings, an alternative strategy is proposed using repeat testing to establish the peak performance score. To date, the shuttle run test has been one of the few maximal tests of physical fitness which is commonly accepted on the basis of a single trial. This practice is unsupported by any scientific evidence and is contrary to evidence from other maximal fitness tests (for example, the grip strength test, standing broad jump or the sit and reach test), which all use the best score from 2 to 3 repeat measurements (Eurofit, 1993). It is recognised that few individuals will actually obtain a maximal performance on their first attempt of such tasks. The shuttle run test differs in that it is an exhaustive test and subjects require time to recover between trials, however the importance of performing repeat trials to gain a good index of maximal performance is no less pertinent. It may be particularly important when used for testing general populations (as opposed to athletic groups) where motivation to run to exhaustion may be poor. Results indicated that repeat testing may partly compensate for some of the day to day variability in individual performance and has been shown to improve the predictive power of the shuttle run test by up to 19% in boys and 20% in girls. It is recommended that for assessing peak oxygen uptake from shuttle run performance, at least 2 repeat tests are performed, conducted two to three days apart.

Multiple regression analysis was used to determined the extent to which the 20m shuttle run test could predict peak oxygen uptake in children. Results indicated that the best predictor of VO_2 peak, in boys, was shuttle run performance in conjunction with the sum of the triceps and subscapular skinfold thickness (R^2= 0.60 to 0.68, with 1 to 3 repeat tests). For girls the best predictor of VO_2 peak was shuttle run performance in conjunction with the triceps skinfold thickness measure (R^2=0.79 to 0.85, with 1 to 3 repeat tests). It was noted that in the case of girls, the use of anthropometric measures within the predictive equation improved predictive power to a level that was equivalent to that of repeat testing. In cases where repeat testing can not be performed, skinfold thickness measures must be included within the test procedures and analysis.

In view of the findings, the first null hypothesis (A_0) which stated that the prediction of VO_2 peak from shuttle run performance would not be improved by the inclusion of anthropometric measures within the prediction equation is rejected. Prediction of VO_2 peak in children, 13 to 14 years was significantly improved by utilising 20m shuttle run test scores in conjunction with skinfold thickness measures.

The second null hypothesis (B_0) stated that prediction of VO_2 peak from shuttle run performance would not be improved by repeat testing. This is also rejected. Repeat testing yielded significant improvement in the predictive power. This was greatest for those predictive equations where anthropometric measures were not considered.

7.1.2 Implications of the research findings

Very little information regarding good practice for shuttle run testing has previously been available. A number of methodological issues were highlighted during the course of this investigation and these need to be addressed carefully if the reliability of the shuttle run test is to be promoted. The following guidelines are proposed:

a) To date there has been a lack of distinction between using the shuttle run test to monitor athletic populations and using it within general population surveys. The latter group may be less practised in pacing and turning techniques and may be less motivated to run to exhaustion. In view of this, a minimum of 2 repeat tests are recommended. This encourages children to compete against their own score and thus push for a maximum. It also helps to compensate for children having "off days".

b) The inclusion of skinfold thickness measures within the shuttle test regression equation can significantly improve prediction of VO_2 peak in children. Skinfold thickness measures are a popular index of body composition and provided that the tester is trained in the techniques of measurement it offers a reasonable estimate of body fat content (Slaughter et al, 1990). It is quick and easy to record in the field using a set of specially devised measurement calipers and following a standardised assessment protocol (Lohman et al, 1991). The current study indicated that the inclusion of selected skinfold thickness measures aided prediction of VO_2 Peak by 16 - 37% (R^2=0.42 for both sexes when using maximal shuttle run speed alone, compared with R^2=0.58 and R^2=0.79 (males and females respectively) using maximal shuttle run speed in conjunction with skinfold thickness measures). Multiple regression analysis was performed to evaluate the use of standard skinfold thickness measures in conjunction with repeat tests of shuttle run performance and the following equations are recommended for predicting VO_2 peak in 13 to 14 year old children (See below). Cross validation of these equations has indicated good predictive power, (root mean square error, 4.35 ml.Kg.$^{-1}$min^{-1}) and prediction is consistent across a wide performance spectrum.

For males: Y (VO_2 Peak, ml.Kg^{-1} min^{-1}) = 4.15 (Maximal shuttle speed, best of 2 tests, km.h^{-1}) - 0.39 (Sum triceps & subscapular, mm) + 10.28

For females: Y (VO_2 Peak, ml.Kg^{-1} min^{-1}) = 6.3 (Maximal shuttle speed, best of 2 tests, km.h^{-1}) - 0.63 (Triceps, mm) - 15.4

c) The use of a peak heart rate measure during the test can help in determining "maximal effort" but as indicated in the current study, it makes test administration more complex and is not ideal when used in isolation. Other physiological indices of maximal performance are required to support it (lactate measures, respiratory quotient, plateau in oxygen consumption) but none of these measures are conducive to field measurement. An alternative and simpler tool to help determine maximal effort is the Borg Scale, Rating of Perceived Exertion (Borg, 1982). This could be incorporated relatively easily into the test procedures and its use in shuttle run testing should be investigated.

The following points relate to general test administration. They are based on experience gained during the study and may be useful for researchers using the test for the first time.

d) The test should be administered indoors, where environmental conditions are relatively stable and using a flat, non slip running surface. As with all fitness assessments, subjects should wear lightweight, non restrictive clothing along with well fitting training shoes. They should avoid eating 1½ to 2 hours before the test.

e) The 20 metre length should be clearly marked at both ends (a straight, continuous line of coloured tape is ideal) and should be placed away from walls or edges thus preventing subjects from using these surfaces to aid turning. Initial pilot trials of the shuttle run test with undergraduate students indicated that pushing off a wall on turns could affect performance and general observation suggested that it created more subject variance in terms of technique. Styles of turning and metabolic requirement is a topic worth further research. The test, however, is best standardised by keeping the shuttle lengths clear of walls and edges.

f) Subjects should be tested in small groups (6-10) and readily identified by the testers (sports bibs or numbered tops may be helpful). This means that individuals can be given encouragement as necessary during the test and their position at the end noted down quickly. Ideally individuals of similar running ability should be placed in the same groups. This can be determined according to previous performance (if known), or on the advice of the school PE staff. Such a procedure encourages friendly rivalry and reduces the likelihood of one fit individual having to complete the test predominantly on their own. It also avoids making less able subjects feel there is no point to their trying.

g) Children should be encouraged to compete against themselves and not to simply follow their friends. "Best friends" who tend to run together as a group rather than as individuals should be placed in different test sessions. Again, this judgement can be based on previous experience or on the recommendation of the PE staff.

h) There is a skill to turning at speed and also to pacing oneself for endurance. Both are important factors contributing to shuttle test performance. Subjects should be allowed to practice turning and pacing themselves prior to starting the test. This should help minimise the confounding effect of poor technique.

7.1.3 Recommendations for future research

i. One of the main issues in using the shuttle run test for assessing peak oxygen uptake is ensuring that subjects are motivated for maximal performance. When testing general populations (as opposed to athletic groups), subjects who are unconditioned, who are unused to running or pacing themselves, or who see "no purpose to the test" may be more likely to drop out from the test early rather than push themselves to exhaustion. Use of the Borg's rating of perceived exertion scale (Borg, 1982) may help to determine whether maximal performance has been achieved. Future investigation should examine the extent to which the use of this scale may improve prediction of peak oxygen uptake from shuttle run performance.

ii. The current study examined the prediction of peak oxygen uptake from shuttle run performance within a restricted age group of children (13 to 14 years). The relationship between peak oxygen uptake and shuttle run performance in other age groups should be examined in order that the test may be applied more widely across the school years. Barnett and colleagues (1993) developed prediction equations for estimating VO_2 peak in children 12 to 17 years. It is unlikely, however, that a single equation can account for the wide maturational differences in children of that age. The extent to which maturation and growth may influence performance is still unclear and future investigation should examine the influence of both maturational age and chronological age on shuttle test performance.

7.2 PHASE 2: Evaluation of methods of heart rate data analysis as a measure of physical activity in children

7.2.1 Research summary

This study addressed two major issues within physical activity assessment. Firstly, it questioned the number of days of continuous heart rate measurement necessary to gain an accurate index of weekly activity levels in children. To date, most researchers have accepted 3 to 4 days of heart rate data as sufficient indication of general activity levels (Atkins et al, 1995; Durant et al, 1993, 1992; Livingstone et al, 1992; Armstrong et al, 1991, 1990) but it is unclear whether such measures are appropriate or whether they can be compared against current activity guidelines which are commonly expressed in terms of weekly participation (Sallis & Patrick, 1994). Secondly, it examined different methods of heart rate data analysis in order to establish which methods are most effective in identifying "active" periods. Many different methods are currently used but it remains unclear which provide the best index of activity levels in children or how these relative indices might compare. Physical activity was assessed by both continuous heart rate monitoring (Polar Electro 4000, Finland) and activity diaries (Durnin & Passmore, 1967) in a group of 28 children. The monitoring period covered seven days (Monday to Sunday) of a typical school week. Data covering a seven day period has been previously reported for adults (Gretebeck & Montoye, 1992), but few studies have covered such an extensive period of measurement in children.

Results from the current study indicated that children's heart rate activity levels were extremely variable from day to day, many children being highly active on some days, very sedentary on others (Range 0-7 days). In general, activity levels based on just 3 to 4 days of monitoring did not provide an accurate indication of total weekly activity. The study examined the effects of taking just four days of heart rate data from within the week of monitoring; if those days where children were "most active" were selected, activity levels for 17 of the children were correctly identified. If, however, children's "least active" days were selected, activity levels for only 2 children were correctly identified and the level of error ranged from 44 to 100%.

Thirteen of the children, rather than 2 could potentially have been classified as sedendary. Unless researchers can be assured that the days monitored give a comprehensive index of a child's total weekly activity, comparison against existing guidelines is inappropriate. The current study found little to recommend recording for less than 6 days and the best measure of week long activity levels was undoubtedly obtained by assessing heart rate over a full seven day period. Null hypothesis C_0 is rejected.

This finding raises important methodological considerations. It is accepted that the recording of heart rate data over a prolonged 7 day period may be impractical and that few children may be compliant with such requirements. As an alternative it is proposed that researchers strive for a seven day heart rate record but allow children to remove the monitors during prolonged sedentary periods, e.g. when watching television during the evenings. Such a procedure is likely to be most effective if heart rate monitors are used in conjunction with activity diaries where the diaries will provide continuous record of all activity during waking hours and ensures that no significant periods of activity are undertaken whilst the monitor is removed. In this case, the heart rate data may be less continuous, or of shorter duration each day, but will enable more days to be achieved and will provide a record of all major periods of moderate to vigorous activity undertaken over the week of testing. The diary/heart rate monitor combination works effectively together in that each set of data can back up and/or clarify the other; erroneous values within the heart rate data are readily made apparent by the activity diary reports whilst the heart rate data provides an objective scale of intensity for each "active" bout and thus checks for over exaggeration of reported activity within the diaries.

Researchers have employed a wide variety of methods of heart rate analysis and several of the most popular methods were examined within the current study:

- ◊ Number of 5, 10 & 20 min periods with HR>119, 139 and 159 $b.min^{-1}$
- ◊ Number of 5, 10 & 20 min periods with HR> tickover plus 20, 30 & 50 $b.min^{-1}$
- ◊ Number of 5, 10, & 20 min periods with HR>125, 150 & 175% of tickover.
- ◊ Number of 5, 10 & 20 min periods with HR>50 & 75% heart rate reserve.
- ◊ Total number of elevated heart rates (irrespective of duration).

No one method emerged as the "best approach" to heart rate data analysis. Most showed moderate to good correlation with reported activity levels (maximum r=0.68, n=28). Distinct sex differences in the patterns of activity were however, noted. Overall activity times were similar for males and females, but males engaged in more sustained and vigorous bouts of activity whilst girls activity was characterised by short burst of moderate activity. In males, the best correlate with reported activity was the number of 5 min periods with heart rate greater than 139 $b.min^{-1}$ or greater than 50% heart rate reserve (r=0.80, n=12). In girls, strongest correlation was yielded by the total number of moderate intensity heart rate recordings (total HR> baseline plus 50 and total HR>175% TOHR, r=0.68, n=12). It is recommended that irrespective of which method of heart rate data interpretation is employed, researchers must examine both sustained periods of activity and total activity (i.e. the sum of all elevated heart rate readings irrespective of the duration).

As resting heart rate data was not available for this group of children, a new method for determining a resting heart rate equivalent was devised. This method determined baseline heart rate by the lowest 15 minute moving average from each daily heart rate recording (labelled as the "tickover" value, TOHR, b.min^{-1}). The tickover method presents a promising development in heart rate data analysis. It provides an individualised measure of baseline heart rate activity and enables individual differences in the fitness and heart rate response to exercise to be considered within the heart rate analysis. The technique has several advantages over standard resting heart rate measures that make it a more attractive index within continuous heart rate studies. As it relies purely upon records of continuous heart rate data, it is easily measured in the field and it does not require children to fast or to have the intrusion of clinical measurement first thing in the morning. Furthermore, it can be readily applied to existing heart rate data. Many larger studies have been unable to record resting heart rate due to constraints of time and resources (Armstrong et al, 1991, 1990) and data analysis has been restricted to examining heart rate levels relative to a set cut off point (typically 139 and 159 b.min^{-1}). Individual tickover heart rates are easily identified and such data could be readily re-examined relative to the tickover measure, thus making allowance for individual variation in resting and active heart rate levels for given intensities of activity.

Other methods have been used to assess baseline heart rate from continuous heart rate data but none appear to demonstrate the strong reliability and validity of the tickover value. Methods using the values of the lowest heart rate recordings (Janz et al, 1992; Freedson, 1989) are easily influenced by isolated erroneous data readings

(Durant et al, 1993, 1992). Since the tickover heart rate is an averaged value, taken over a continuous 15 minute period, it is much less susceptible to weighting by artifact data. Mean heart rate during sleep, as used by Atkins and colleagues (1995) is a good alternative, but the requirement for extended wear of the monitors over a 24 hour period limits its application within larger scale studies and it is unlikely to be popular with subjects.

As shown by a series of short pilot studies there is a strong correlation between the tickover heart rate and actual resting heart rate levels (r=0.68-0.97, see Appendix II) and it is stable for individuals over time (R=0.63, n=28, across 7 days of assessment). The evidence supports the tickover as an effective measure of baseline heart rate and as such it provides a simple and effective means for determining the relative intensity of heart rate activity.

7.2.2 Implications of the research findings

a) The majority of heart rate monitoring studies assess activity levels using 3 to 4 days of measurement (Livingstone et al, 1992; Armstrong et al, 1991, 1990; Riddoch et al, 1991b). Evidence from the current study supports previous findings in adults (Gretebeck & Montoye, 1992) which indicates considerable day to day variance in activity levels and recommends a minimum of 6 days of measurement. It is suggested that physical activity measurement should be approached with similar rigour as the assessment of energy expenditure by food intake which requires a seven day measurement (Garrow, 1974). If activity measures are to be evaluated against current activity guidelines, heart rate activity must be expressed relative to a weekly index. Ideally the monitoring period should extend across a full 7 days, this procedure providing greatest assurance that all active periods through the week are included. If this is impractical it is important to ensure that all active periods undertaken within the week of testing are covered. This may mean compromising the duration of the total daily recording time in favour of covering all active periods but will provide a better estimate of significant moderate to vigorous activity time.

b) Whilst heart rate data provides detailed information on the intensity, frequency and duration of activity, it can not indicate mode of activity. In order to obtain information on the types of activity undertaken, heart rate monitoring should be used in conjunction with other appropriate means of activity assessment e.g. activity diaries. In addition to providing a more detailed record of activity, this procedure offers opportunity for cross checks between the two sources of information. Researchers may wish to draw on other sources of information to further substantiate the diary and heart rate records (school timetables, daily interview with subjects).

c) Heart rate activity may be interpreted using a variety of methods. Most measures show moderate to good correlation with reported activity levels but it should be noted that different indices will identify different levels of exercise intensity (See Table 7.1). The selected method of analysis will depend on which levels of intensity the researcher is interested in investigating. Which ever cut off procedure is chosen it is recommended that researchers examine both the number of sustained active periods and the total number of elevated heart rates.

Table 7.1 The relative intensity of popular heart rate activity indices

Intensity	Heart rate index
Low	Baseline heart rate plus 20 $b.min^{-1}$ Baseline heart rate plus 30 $b.min^{-1}$ 125% Baseline heart rate 150% Baseline heart rate
Moderate	Baseline heart rate plus 50 $b.min^{-1}$ 175% Baseline heart rate Heart rate greater than 119 $b.min^{-1}$
Moderate to Vigorous	Heart rate greater than 139 $b.min^{-1}$ Heart rate greater than 50% heart rate reserve
Vigorous	Heart rate greater than 159 $b.min^{-1}$ Heart rate greater than 75% heart rate reserve

d) It was noted that total activity levels for males and females were similar but that boys tended to engage in more sustained bouts of activity. There may be distinct sex differences in the patterns of physical activity in children. Methods of heart rate data analysis must be sensitive enough to detect these differences with particular regard to differences in both intensity and duration of activity.

e) In view of the lack of standardised procedures, and as a matter of good practice, it is recommended that researchers clearly specify which analytical methods they have used, taking care to note the intensity cut off and the target duration of active bouts.

f) Whilst gaining physical activity estimates based on a week long measure will be most in line with current physical activity guidelines, this procedure will not account for fluctuations in activity levels across the year. Researchers may wish to consider the use of questionnaire surveys to gain overall view of participation in activity over longer periods. Ideally, this would be supported by heart rate data (or other objective index of activity) assessed at strategic points.

7.2.3 Recommendations for future research

i. The seven day continuous heart rate measure has been shown to provide an accurate index of week-long activity. It is unclear however how much activity varies from week to week or across months and seasons. Further research should examine variance in activity over longer periods of time. It would be interesting to examine heart rate activity levels in the same group of children across the spring, summer, autumn and winter months.

ii. The tickover heart rate has been proposed as a practical method of determining baseline heart rate from continuous heart rate records. Pilot work has been encouraging showing strong correlation between tickover heart rate and resting heart rate measures ($r=0.68$-0.97) and showing reasonable stability of tickover readings across several test days ($R=0.63$, $n=28$). Further validation of the tickover heart rate as a measure of baseline heart rate is required, in particular assessing the possible effects of age, fitness status and habitual physical activity levels.

iii. The current study used heart rate data with monitors set to record on a minute by minute basis. The volume of data generated by heart rate data is considerable and taking minute by minute recordings has become common practice within heart rate monitoring research (Livingstone et al, 1992; Durant et al; 1993, 1992; Armstrong et al, 1991, 1990; Riddoch et al, 1991b). Nevertheless, it does mean that the majority of pulse rate readings generated throughout the period of monitoring will not be recorded. Further research should examine whether the recording interval is significant in determining the heart rate activity measure. Polar Electro monitors (Finland) have the facility to record heart rate every 5 or 15 seconds and could be readily used to investigate this.

7.3 PHASE 3: A descriptive survey of aerobic fitness and physical activity patterns of Edinburgh school children, aged 13 to 14 years.

7.3.1 Research summary

This section presented a descriptive survey of fitness and physical activity patterns in Edinburgh school children, aged 13 to 14 years. Selected measures included anthropometric measures, shuttle run performance and physical activity assessed by both continuous heart rate monitoring and activity diaries. Each of the measures was carefully reviewed within preliminary investigations and demonstrated good standards of reliability and validity. The sample size was relatively small (n=91) but this enabled an extensive volume of heart rate data to be obtained (4-7 days for each child) and ensured that the quality of the data could be rigorously controlled.

Aerobic fitness was assessed by shuttle run performance and peak oxygen uptake determined by prediction equations developed specifically for this age group of children. Boys obtained significantly more laps in the shuttle run test than girls (mean difference, 22 laps) and had significantly higher predicted peak oxygen uptake (mean difference, 8.1 $ml.Kg^{-1}.min^{-1}$). This supports previous findings (Armstrong et al, 1991, 1990, 1988; Shvartz & Reibold, 1990; NIFS, 1989; Leger et al, 1988; Krahenbuhl et al, 1985). The null hypothesis (D_0) which stated that there would be no significant sex difference in aerobic performance is rejected.

Physical activity patterns were assessed by continuous heart rate monitoring and activity diary, measured over a seven day period. Mean time spent in moderate to vigorous activity was 211(+/-154) minutes over one week, an average of approximately 30 minutes per day for both boys and girls. Boys engaged in significantly more sustained periods of moderate to vigorous activity (95 mins per week with HR>139$b.min^{-1}$, compared with 60 minutes for girls). The null hypotheses (E_0) however, which states that there is no difference in the levels of physical activity cannot be rejected outright. Girls showed similar levels of overall moderate activity but tended to engage in short bursts of activity (less than 5 minutes duration) rather than sustained periods of activity.

Levels of activity for the subject group were compared against current physical activity guidelines (Sallis & Patrick, 1994). Approximately 70% of boys and 50% of girls fulfilled the current recommendations for the volume of moderate activity (>210 minutes per week), however few maintained regular participation in daily activity and most tended to have very active days interspersed with very inactive days. A similar level of children attained the recommended levels for participation in sustained moderate to vigorous activity (3 or more bouts of 20 minutes duration or longer). A tendency for children to be either very active or very inactive was noted and this was particularly prominent for boys. Clearly, whilst many children are extremely active and may be considerably more active than adult groups (ADNFS, 1992) there are many who are not taking sufficient exercise. The challenge to health promotion is encourage the least active groups, young girls especially, to increase their levels of sustained moderate activity and to encourage more children to make exercise part of daily routine.

Whilst this study has enabled evaluation of the levels and patterns of activity in Edinburgh children, and highlighted areas of concern, it remains unclear how levels of participation might be promoted. The evidence presented here suggests that children gain most of their activity through school, both as part of school PE and during recreational breaks, and that more should be done to encourage greater participation in after school activities. Girls participated in less "out of school" activity than boys and for some their "out of school" activity was found to be of limited intensity and duration. Many girls reported participating in "dance/exercises" in their spare time but these unstructured activities, carried out at home and without supervision were rarely sustained at a sufficient intensity or duration to benefit cardiovascular health. Many girls appear to want to exercise and improve their fitness level but clearly the quality of the "workout" may at times be poor. Teenage girls might benefit from the provision of more structured activities after school.

7.3.2 Implications of the research findings

a) Many children, particularly boys are very active. Approximately 70% of boys and 50% of girls fulfil current recommendations for participation in moderate and vigorous levels of physical activity. Whilst these levels of vigorous level activity are in line with findings from other countries, levels for moderate level activity appear to be lower, particularly for girls. Pate and colleagues (1994) report greater than 80% of children achieving the recommended levels of moderate activity. The disparity may be partly due to the more sensitive measures adopted within the current survey (heart rate monitoring rather than questionnaire) and the fact that levels of activity were assessed in terms of sustained periods of activity (>5 minutes duration). When total activity was examined, in addition to sustained periods of activity, there was no significant difference in the levels of activity for males and females ($p>0.05$). This has two major implications, firstly that the patterns of activity for males and females may be very different with girls tending to engage in less sustained, less vigorous but more frequent bouts of activity. Whether this is due to physiological or sociological reasons is unclear and deserves further investigation. Secondly, the findings indicate that there are still a considerable number of children (at least 30% of both males and females) who do not take sufficient levels of moderate and vigorous exercise.

b) Children's activities tend to be sporadic with very active days interspersed with very inactive days. The current recommendations indicate that children should engage in activity on most, if not all, days of the week. More should be done to encourage **daily** participation in moderate level activity. Further research however is necessary to establish whether there are important differences (in terms of health) between those individuals who take daily exercise and those who achieve the total recommended levels but are sporadically active. It may be that due to the nature of life, participation in daily activity is unrealistic, in which case the current guidelines may be inappropriate.

c) More emphasis should be placed upon those children engaging in very low levels of activity and encouraging increased participation in moderate level activities. Girls in particular should be encouraged to engage in more "out of school" activities. The provision of structured after school activities may be helpful

d) Heart rate analysis indicated that the highest (mean heart rate, 140-165 $b.min^{-1}$) and most sustained periods of heart rate activity were generally achieved during participation in team sports (predominantly, football, rugby, and hockey). During other activities, such as cricket, table tennis, cycling and gymnastics, heart rate levels were lower and more sporadic (mean heart rate, 115-130 $b.min^{-1}$). It was noted that some children may go through a 35 minute physical education lesson without elevating heart rate above 130 beats per minute. This is in line with findings from a review of children's heart rates during physical education lessons (Stratton, 1996) which indicates that the majority of lessons do not stimulate appropriate amounts of moderate to vigorous activity (specified as 50% of total lesson time, Public Health Service, 1991). Physical Education has many aims in addition to the promotion of physical fitness, for example, the development of motor skills, social interaction, health promotion and the actual intensity of the lesson may not be of primary importance on a particular teaching day. Teaching staff however should be made aware of how little exercise some children can take during a normal class and note that if this is contrary to the aims of the lesson, classes must be reviewed and adjusted accordingly.

e) Team sports play a prominent role within the PE curriculum (Armstrong, 1990b; Dowling, 1987), and as indicated by the heart rate monitoring patterns exhibited within the current study, they are clearly important in boosting many children's activity levels and fitness. They are however difficult to sustain outwith the structured settings of schools and clubs. The requirement for other players (a game of rugby would require recruiting up 29 enthusiastic others) means that spontaneous games during leisure time are difficult to initiate. Team based activities are thus less conducive to the development of lifelong participation in sports as most children do not pursue team sports after leaving school. The Scottish Sports Council Survey (1992) showed that the most popular sports for adults (listed in descending order of popularity) were walking, swimming, keep fit/aerobics, snooker, football, dancing, golf, cycling, running/jogging and multigym. From this top ten activities, football was the only team game and its place on the ranking was due only to the large number of males participating in the game. A survey by the Physical Education Authority (PEA, 1987) noted that teachers placed increased importance upon health related fitness as a major objective of the physical education programme, this view held despite more time being allocated to traditional team games within the PE curriculum. Ten years on and the situation seems unchanged; the recent Government proposals laid out in the document "Scotland's Sporting Future - A New Start" (July 1995) places increased emphasis upon developing children's participation in team sport. It was the Governments recommendation that the revised PE curriculum, as from August 1995, should have "an enhanced role for team games"(Dept of National Heritage, July 1995). Whilst team sport is no doubt important and can play a useful role in the physical development and socialisation of children and adolescents, it is questionable whether it is essential or a priority within health promotion strategy. If setting the foundations for lifelong participation in regular physical activity is a primary target for education, it is necessary to consider the needs of the "least active" and focus efforts upon encouraging increased participation by them.

7.3.3 Recommendations for future research

i. Whilst overall levels of activity were similar for males and females, boys tended to engage in more sustained bouts of activity and girls in more frequent bouts of short duration activity. It is unclear why this difference in the patterns of activity for males and females patterns exists or whether it is important in terms of future participation in exercise and future health.

ii. The strongest correlation between aerobic fitness and physical activity measures was r=0.44 for males (No. of 10 min periods with HR>50% HRR and maximal shuttle speed) and 0.35 for females (No. of 5 min periods with HR>159b.min^{-1} and number of shuttle run laps). These are higher than reported by previous studies (Eaton et al, 1995; Pate et al, 1990) and may have been achieved in part by the more rigorous techniques used for assessing physical activity levels. Further research should endeavour to explore this relationship in more detail to establish the direction of the relationship (i.e. are fit children more active or are active children more fit?) and to examine which types of activity are most important for the maintenance of fitness and/or good health.

iii. The current study presents data for a selected sample of state and independent school children in Edinburgh. In order to make a stronger statement regarding the activity levels of Scottish children it is necessary to conduct a larger scale survey on a nationally representative sample and across a wider age range. This would also enable analysis to be extended to examine regional differences in patterns of exercise and differences between urban and rural populations.

iv. The techniques adopted within the current investigation may be usefully applied to examine seasonal differences in children's activity. In particular, it would be useful to determine patterns of activity over the school vacation period.

v. The small size of the current investigation has limited the extent to which mode of exercise could be examined. More detailed evaluation of modes of exercise is warranted with particular regard to establishing which activities are most popular for males and females, what motivates children to chose particular types of activity, which activities elicit the highest and most sustained heart rates and which are most beneficial to health and/or fitness.

vi. Swimming activity could not be recorded during the current investigation due to excessive data interference when monitors were placed in a water based environment. Previous studies have also had to exclude swimming activities (Janz et al, 1992; Riddoch et al, 1991b). Given the popularity of this activity in children, future research should endeavour to develop improved methods of assessment to enable this type of activity to be evaluated. Predictive tables (Brooks and Fahey, 1985) are insufficient due to the wide variance in the intensity of swimming activity when performed by different individuals in different settings.

vii. It is of particular importance to identify (and break down), the barriers which prevent sedentary children taking part in regular activity. Future research should focus on establishing whether there are critical periods when activity levels may drop, which individuals are most at risk and establish how best to get sedentary individuals back into the exercise habit.

REFERENCES

AAHPERD (1988) Physical best test manual. American Alliance for Health, Physical Education, Recreation and Dance. Reston, VA.

Aaron, D.J.; Kriska, A.M; Dearwater, S.R; Anderson, R.L; Olsen,T.L; Cauley, J.A; Laporte, R.E. (1993) The epidemiology of leisure physical activity in an adolescent population. Med.Sci.Sports Ex. 25 (7): 847 - 853.

Acheson, R.J; Campbell, I.T; Edholm, O.G; Miller,D.S; Stock, M.J.(1980) The measurement of daily energy expenditure - an evaluation of some techniques. Am.J.Clin.Nutr. 33:1155-1164.

Alderson, M.R. & Yasin, S.(1966) Measuring habitual leisure time activity: a questionnaire method suitable for epidemiological studies. In Evang & Anderson (Eds) Physical activity in health and disease: 215-221. Williams & Wilkins Co. Baltimore.

Allied Dunbar National Fitness Survey. Summary Report (1992). Sports Council & Health Education Authority, London.

American College of Sports Medicine (1993) Position stand on physical activity, physical fitness and hypertension. Med.Sci.Sports Ex., 25, i-x.

American College of Sports Medicine (1990) The recommended quantity and quality of exercise for developing and maintaining cardiovascular and muscular fitness in healthy adults. Med.Sci.Sports Ex. 22 (2): 265-274.

Amsterdam Growth Study: A Longitudinal Analysis of Health, Fitness and Lifestyle (1995) Kemper, H.C.G. (Ed.) Human Kinetic Publishers, Champaign, Il.

Armstrong, N. & McManus, A. (1994) Children's fitness and physical activity - A challenge for Physical Education. British Journal of P.E.,25 (1) Spring: 20 - 26.

Armstrong, N. & Bray, S. (1991) Physical activity patterns defined by continuous heart rate monitoring. Arch.Dis.Child. 66: 245-247.

Armstrong, N.; Williams, J; Balding, J; Gentle, P.; Kirby, B. (1991) Cardiopulmonary fitness, physical activity and selected coronary risk factor variables in 11 to16 year olds. Ped. Ex.Sci. 3,(3): 219-228.

Armstrong, N. (1990) Children's physical activity patterns: Implications for Physical Education. In N. Armstrong (Ed) New Directions in Physical Education, Volume 1: 1-15. Human Kinetic Publishers, Champaign, Il.

Armstrong, N.; Balding, J.; Gentle, P.; Williams, J.; Kirby, B. (1990) Peak oxygen uptake and physical activity in 11 to 16 year olds. Ped. Ex.Sci., 2: 349 - 358.

Armstrong, N. (1989) Children are fit but not active! Education and Health, 7 (2): 28-32.

Armstrong, N.; Williams, J.; Ringham, D. (1988) Peak oxygen uptake and progressive shuttle run performance in boys aged 11 to 14 years. Brit.J.of P.E.Research Supplement. 19,(4): 10-11.

Armstrong, N. & Davies, B. (1984) The physiological and metabolic responses of children to exercise. Physical Education Review, 7, 90-105.

Astrand, P-O & Rodahl, K. (1986) Textbook of Work Physiology: Physiological bases of exercise (3rd Ed.) McGraw Hill.

Astrand, I. (1960) Aerobic work capacity in men and women with special reference to age. Acta.Physiol.Scand. 49 (Suppl): 432 - 436.

Astrand, P-O (1952) Experimental studies of physical working capacity in relation to sex and age. Ejnar Munksgaard, Copenhagen.

Atkins, S.; Dugdill, L.; Phillips, R.; Reilly, T.& Stratton, G.(1995) The use of whole day (24Hr) heart rate monitoring in assessing physical activity patterns and aerobic fitness thresholds in school children. BASES Conference Abstract, Queens University of Belfast.

Atwater, W.O. & Benedict, F.(1903) Experiments on the metabolism of matter and energy in the human body. Bulletin No.136. Washington DC, USDA Office of experimental studies.

Balding, J.(1988) Young people in 1988. Schools Health Education Unit, England.

Bale P. (1981) Pre and post adolescents' physiological response to exercise. Brit.J.Sports Med. 15: 246 - 249.

Bale P.(1978) The physiological performance of pre-adolescent school children. Physical Ed.Rev.1:89-95.

Baranowski, T.; Bouchard, G.; Bar Or, O.; Bricker, T.; Heath, G.; Kimm, S.Y.S.; Malina, R.; Obarzanek, E.; Pate, R.; Strong, W.B.; Truman, B.; Washington,R. (1992) Assessment, prevalence and cardiovascular benefits of physical activity and fitness in youth. Med.Sci.Sports Ex. 24, 6 (Suppl): S237-S247.

Baranowski, T. (1988) Validity and reliability of self report measures of physical activity: an information processing perspective. Res.Q.Ex.Sport. 59: 314-332.

Baranowski, T.; Dworkin, R.J.; Cieslik, C.J.; Hooks, P.; Clearman, D.R.(1984) Reliability and validity of self report of aerobic activity; family health project. Res.Q.Ex.Sport. 55: 309-317.

Barnett, A.; Chan, L.Y.S.; Bruce, I.C.(1993) A preliminary study of the 20m shuttle run as a predictor of peak VO2 in Hong Kong Chinese students. Ped. Ex.Sci. 5: 42 - 50.

Bar Or, O. (1989) Trainability of the prepubescent child. The Physician and Sports Medicine, 17 (5): 65-83.

Bar Or, O. (1987) A commentary to children and fitness: A public health perspective. R.Q.Exer.Sport. 58,(4): 304 - 307.

Bateman, S.C.; Goldsmith, R.; Jackson, K.F.; Ruffell Smith, H.P.; Mattocks, V.S. (1970) Heart rate of training captains engaged in different activities. Aerospace Med. 41, (4): 425 - 429.

Baxter Jones, A.D.G. & Helms, P. (1995) Are objective criteria of peak oxygen uptake in children necessary to assure true maximal effort. Conference Abstract. BASES Annual Conference, Queens University Belfast.

Benedict, F. & Milner R. (1907) Experiments on the metabolism of matter and energy in the human body. Bulletin No.175. Washington DC, USDA Office of Experimental Studies.

Berlin, J.A. & Colditz, G.A. (1990) A meta analysis of physical activity in the prevention of coronary heart disease. Amer.J.Epid. 132: 612 - 628.

Beunen G. & Malina, R.M. (1988) Growth and physical performance relative to the timing of the adolescent spurt. Ex.& Sport Sci. Reviews 6, 503 - 540.

Biddle, S. & Mutrie, N.(1991) Psychology of physical activity and exercise: A health related perspective. Springer Verlag. London.

Binkhorst, R.A.; Saris, W.H.M.; Noordeloos, A.M.;.van't Hof, M.A; de Haan,A.F.J. (1986) Maximal oxygen consumption of children (6 to 18 years) predicted from maximal and submaximal values in treadmill and bicycle tests. In Rutenfranz J., Mocellin & Klimt (Eds), Children and Exercise XII, International Series on Sports Science, Vol. 17: 227 - 232. Human Kinetic Publishers, Champaign, Il.

Blair, S.N & Connelly, J.C.(1994) How much physical activity should we do? The case for moderate amounts and intensities of physical activity. In, Moving On: International Perspectives on Physical Activity. Health Education Authority:18-34. HEA, England.

Blair, S.N. (1994) Physical activity, fitness and coronary heart disease. In, C.Bouchard, R.J.Shephard & T.Stephens (Eds) Physical activity, fitness and health: 579-590. Human Kinetics, Champaign, Il.

Blair S.N. (1993) C.H.McCloy Research Lecture: Physical activity, physical fitness and health. Res.Q.Ex.Sport. 64,(4): 365 - 376.

Blair, S.N. (1992) Are American children and youth fit? A need for better data. Res.Q.Ex.Sport. 63 (2): 120 -123.

Blair, S.N.; Kohl, H.W. & Gordon, N.F.(1992) Physical activity and health: A lifestyle approach. Med.Ex.Nutr.Health.1: 54-57.

Blair, S.N.; Kohl, H.W.; Paffenbarger, R.S.; Clark, D.G.; Cooper, K.H.; Gibbons, L.W.(1989) Physical fitness and all cause mortality. A prospective study of healthly men and women. JAMA. 262, (17): 2395 - 2401.

Blomqvist, C.G. & Saltin, B.(1983) Cardiovascular adaptations to physical training. Ann.Rev.Physiol. 169-189.

Boreham, C.A.G.; Savage, J.M.; Primrose, D.; Cran, G.; Strain, J. (1993) Coronary risk factors in children. Arch. Dis.Childhood. 68: 182-186.

Boreham, C.A.G.; Paliczka, V.J.; Nicholls, A.K.(1990) A comparison of the PWC170 and 20 MST tests of aerobic fitness in adolescent children. J.Sports Med.Phy. Fitness, 30: 19-23.

Borg, G.A.V. (1982) Psychophysical basis of perceived exertion. Med. Sci. sports. Ex. 14 (5): 377-381.

Borg, G.A.V. (1970) Percieved exertion as an indicator of somatic stress. Scand. J.Rehab. Med. 2: 92-98.

Borms, J. (1986) The child and exercise: An overview. Journal of Sports Science, 4, (1): 3-20.

Bouchard, C.; Shephard, R.J.; Stephens, T. (Eds) (1994) Physical Activity, Fitness and Health: International proceedings and consensus statement. Human Kinetics, Champaign, Il.

Bouchard, C.; Dionne, F.T.; Simoneau, J.A.; Boulay, M.R. (1992) Genetics of aerobic and anaerobic performances. Exer. Sport Sci. Reviews, 20: 27-58.

Bouchard, C. (1991) Heredity and the path to overweight and obesity. Med. Sci. Sports Exer. 23:285-291.

Bouchard,C.; Shephard, R.J.; Stephens, T.; Sutton, J.R.; McPherson, B.D. (1990) Exercise, Fitness and Health: A Consensus of Current Knowledge. Champaign, Il: Human Kinetics.

Bouchard, C.; Trembley, A.; LeBlanc, C.; Lortie, G.; Savard, R. (1983) A method to assess energy expenditure in children and adults. Amer.J.Clin.Nutr. 37: 461-467.

Braden, D.S. & Strong, W.B.(1989) Cardiovascular response to exercise. In, Gisolfi C.V.& Lamb D.R.(Eds) Perspectives in Exercise Science and Sports Medicine, Volume 2, Youth Exercise & Sport: 293-329. Benchmark Press Inc, US.

Bradfield, R.B.; Paulos, J.; Grossman, M.S.; Grossman, L.(1971) Energy expenditure and heart rate of obese high school girls. Amer.J.Clin.Nutr.24: 1482-1488.

Bradfield, R.B.; Chan, H.; Bradfield, N.E.; Payne, P.R.. (1971) Energy expenditures and heart rates of Cambridge boys at school. Amer.J.Clin.Nutr. 24: 1461-1466.

Brettschneider, W.D. (1992). Adolescents, leisure, sport and lifestyle. In Williams, T.; Almond, L. & Sparkes, A. (Eds) Sport and Physical Activity: Moving towards excellence. Proceedings of the AIESEP World Convention. 1990, Loughborough University, 536:550. E.& F.N. Spon, London.

Brooke, J.D.; Hardman, A.E.; Bottomley, F.A.(1975) The physiological load of a netball lesson. Bulletin of P.E. 11,31 - 42.

Brookes, G.A. & Fahey, T.D.(1985) Exercise Physiology: Human bioenergetics and its applications. NY. Macmillan Press.

Brouha, L.; Graybiel, A.& Heath, C. (1943) The step test: A simple method of measuring physical fitness for hard muscular work in adult man. Canadian Review of Biology, 2: 86-91.

Buono, M.J.; Roby, J.J.; Micale, F.G.; Sallis, J.F.; Shephard, W.E.(1991) Validity and reliability of predicting maximum oxygen uptake via field tests in children and adolescents. Ped.Ex.Sci. 3: 250 - 255.

Buono, M.J; Roby, J.J.; Micale, F.G.; Sallis, J.F.(1989) Predicting maixmal oxygen uptake in children: Modification of the Astrand-Ryhming test. Ped.Ex.Sci. 1: 278 - 283.

Cale, L. (1994) Self report measures of children's physical activity: Recommendations for future development and a new alternative measure. Health Ed Journal. 53, 439-453.

Cale, L & Harris, J. (1993) Exercise recommendations for children and young people. Physical Education Review, 2 (16): 89-98.

Campbell,W.C. (1994) The School system and Active Living Programs for Children & Youth. In Quinney et al (Eds) Towards Active Living, 141 - 145. Human Kinetics, Champaign, Il.

Campbell, W.R. & Pohndorf, R.H. (1961) Physical fitness of British and U.S children. J.Phys.Educ. 53, 48 - 52.

Canada Fitness Survey (1983) Canadian youth and physical activity. R.M.Malina. Ottawa, ON.

Carroll, J. & Green, F. (1993) Exercise on prescription: A report of the pilot scheme to prescribe exercise as part of a coronary heart disease prevention programme. Stockport Health Authorities & Stockport Leisure Services Department.

Caspersen, C.J.; Powell, K.E.; Merritt, R.K. (1994) Measurement of health status and well-being. In, Bouchard, C.; Shephard, R.J. & Stephens, T. (Eds) Physical activity , fitness and health - International proceedings and consensus statement. Human Kinetics, Champaign, Il.

Caspersen, C.J.; Powell, K.E.; Christenson, G.M. (1985) Physical activity, exercise and physical fitness: Definitions and distinctions for health related research. Public Health Reports. 100, (2): 126 - 130.

Ceesay, S.M.; Prentice, A.M.; Day, K.C.; Goldberg, G.R.; Murgatroyd, P.R.; Scott, W. (1989) The use of heart rate monitoring in the estimation of energy expenditure using whole body calorimetry: A validation study. Brit.J.Nutr.61: 175-186.

Centers for Disease Control (1992) Vigorous physical activity among high school students. US 1990. MMWR. 41: 91-94. US Dept. of Health & Human Services. Public Health Service.

Central Regional Council & Forth Valley Health Board (1993) Health & fitness of secondary school children aged fourteen: Pilot Study (Final Report). Central Regional Council Education Dept & Forth Valley Health Board Dept of Community Child Health.

Chase, D.R. & Godbey, G.C. (1983) The accuracy of self reported participation rates. Leisure Studies. 2 (2):231 - 236.

Ching, P.L.Y.H. & Dietz, W.H. (1995) Reliability and validity of activity measures in preadolescent girls. Ped.Ex.Sci. 7:389-399.

Christensen, C.C.; Frey, H.M.M.; Foenstelien, E.; Aadland, E.; Refsum, H.E.(1983) A critical evaluation of energy expenditure estimates based on individual oxygen consumption/ heart rate curves and average daily heart rate. Amer.J.Clin.Nutr. 37: 468-472.

Coleman. J.C. & Hendry, L. (1989). Nature of Adolescence. Routledge, London.

Cooper, K.H. (1968) A means of assessing maximal oxygen uptake. JAMA. 203: 135 - 138.

Cooper, K.H.; Pollock, M.L.; Martin, R.P.; White, S.R.; Linnerad, A.C.; Jackson, A.S. (1976) Physical fitness levels verses selected risk factors: A cross-sectional study. JAMA, 236: 116-169.

Corbin, C.B. & Pangranzi, R.P. (1992) Are American children and youth fit? Res.Q.Ex.Sport. 63 (2): 96 - 106.

Crombie H. (1995) Take a Walk. Royal Society for Health. London.

Cureton, K.J. & Warren, G.L. (1990) Criterion referenced standards for youth health related fitness tests: A tutorial. Res.Q.Ex.Sport. 61 (1): 7-19.

Currie, C. & Todd, J. (1990) Health behaviours of Scottish school children. Report 1: National and regional patterns. WHO cross national health behaviour in school age children study. University of Edinburgh, Research Unit for Health & Behaviour Change, Edinburgh.

Dalsky, G.; Stocke, K.S.; & Eshani, A.A. (1988) Weight bearing exercise training and lumbar bone mineral content in post menopausal women. Annals of Internal Medicine, 108: 824 - 828.

Dauncey, M.J. & James, W.P.T. (1979) Assessment of the heart rate method for determining energy expenditure in man using whole body calorimetry. British. J. Nutr. 42: 1 - 13.

Davies, C.M.T.; Barnes, C.; Godfrey, S. (1972) Body composition and maximal exercise performance in children. Human Biol. 44: 195-214.

Davidson, R.C. & Grant, S.(1993) Is walking sufficient exercise for health? Sports Med. 16 (6): 369 - 373.

Dennison, B.A.; Straus, J.H.; Mellits, E.D.; Sharney, E. (1988) Childhood physical fitness tests: Predictor of adult physical activity levels. Pediatrics, 82 (3): 324-330.

Department of Health (1995) More people, more active, more often: Physical activity in England, A consultation paper. Department of Health, Physical Activity Task Force, London.

Department of National Heritage (1995) Sport: Raising the Game. DNH, London.

Dishman, R.K.; Sallis, J.F.; Orenstein, D.R. (1985) Determinants of physical activity and exercise. Public Health Reports. 100: 158.

Doan, R.E. & Scherman, A. (1987) The therapeutic effect of physical fitness on measures of personality: A literature review. J.Counselling & Development, 11: 28-36.

Dowling, F. (1987) A health focus within PE. In Biddle,S (Ed) Foundations of health related fitness in PE, 13-18. London, Ling.

Drinkwater, B.L. (1993) Exercise in the prevention of osteoporosis. Osteoporosis Int. 3, (Suppl 1): S169-S171.

Duncan, J.J.; Gordon, N.F.; Scott, C.B. (1991) Women walking for health and fitness. How much is enough? JAMA. 266: 3295 - 3299.

Durant, R.H.; Baranowski, T.; Davis, H.; Rhodes, T.; Thompson, W.O.; Greaves, K.A.; Puhl, J. (1993) Reliability and variability of indicators of heart rate monitoring in children. Med. Sci. Sports Exer. 25 (3): 389-395.

Durant, R.H.; Baranowski, T.; Davis. H.; Thompson, W.O.; Puhl, J.; Greaves, K.A; Rhodes, T. (1992) Reliability and variability of heart rate monitoring in 3, 4, or 5 year old children. Med.Sci.Sports Exer. 24 (2): 265-271.

Durnin, J.G.V.A. (1992) Physical activity levels - past and present. In Physical Activity and Health, Norgan, N.G. (ed) Cambridge University Press, Cambridge.

Durnin, J.V.G.A. (1971) Physical activity by adolescents. Acta. Paed.Scand.Suppl. 217: 133-135.

Durnin, J.V.G.A. & Passmore, R. (1967) Energy, Work & Leisure. Heinnemann Educational Books Ltd, London.

Edholm, O.C.; Fletcher, J.G.; Widdowson, E.M.; McCance, R.A.(1955) The energy expenditure and food intake of individual man. Br.J.Nutr. 9:286-300.

Education (No. 2) Act. (1986) HMSO, London.

Education Reform Act. (1988) HMSO, London.

Engstrom, L.M. (1980) Physical activity of children and youth. Acta.Paed.Scand. Suppl. 283: 101-105.

Eston, R.G. & Brodie, D.A. (1985) The assessment of maximal oxygen uptake from running tests. Phys.Educ.Review. 8 (1): 26-34.

Eurofit: European Tests of Physical Fitness (1993) Council of Europe Committee for the Development of Sport, Strasbourg, Germany.

Farrally, M.R.; Watkins, J. & Ewing, B.G. (1980) The physical fitness of Scottish schooboys aged 13, 15 and 17 years. The Scottish School of Physical Education, Jordanhill College of Education.

Fentem, P.H. (1992) Exercise in prevention of disease.Brit.Med.Bulletin, 48 (3): 630-650.

Fitness Canada (1981,1983) Fitness and lifestyle in Canada. The Canada Fitness Survey. L.M.Wankel (Ed.), Ottawa, ON.

Fleiss, J. (1986) The design and analysis of clinical experiments. John Wiley & Sons. NY.

Fletcher, G.F.; Froelicher, V.F.; Hartley, L.H.; Haskell, W.L.; Pollock, M.L. (1990) Exercise Standards: A statement for health professionals from the American Heart Association. Special Report. Circulation. 82 (6): 2286 - 2322.

Forth, C.D. & Salomi, A.W. (1988) Relationships among self reported physical activity, aerobic fitness and reaction time. Can.J.of Sports Sciences, 13: 88-90.

Frazer, G.E.; Phillips, R.L.; Harris, R. (1983) Physical fitness and blood pressure in school children. Circulation, 67 (2): 405-412.

Freedson, P.S. & Goodman, T.L. (1993) Measurement of oxygen consumption. In, T.W.Rowland (Ed.) Pediatric Laboratory Exercise Testing: Clinical Guidelines, 91 - 113. Human Kinetics, Champaign, Il.

Freedson, P.S. & Rowland, T.W. (1992) Youth activity verses youth fitness: Lets redirect our efforts. Res.Q.Ex.Sport. 63 (2): 133 - 136.

Freedson, P.S. (1991) Electronic motion sensors and heart rate as measures of physical activity in children. J.School Health. 6: 220-223.

Freedson, P.S. (1989) Field monitoring of physical activity in children. Ped Ex Sci. 1:8-18.

Fripp, R.R.; Hodgson, J.L.; Kwiterovich, P.O.; Werner, J.C.; Schuler, H.G.; Whitman, V. (1985) Aerobic capacity, obesity and atherosclerotic risk factors in male adolescents. Pediatrics, 75: 813-818.

Fuchs, R.; Powell, K.E.; Semmer, N.K.; Dwyer, J.H.; Lippert, P.; Hoffmeister, H. (1988) Patterns of physical activity among German adolescents: The Berlin-Bremen Study. Prev. Med. 17: 746 - 763.

Garrow, J.R. (1974) Energy balance and obesity in man. Elsevier/ North Holland Publishers, Amsterdam.

Getchell, L.H.; Kirkendall, D.; Robbins, G. (1977) Prediction of maximum oxygen uptake in young adult women joggers. Res.Quart. 48: 61 - 67.

Gibbons, L.W.; Blair, S.N.; Cooper, K.H.; Smith, M. (1983) Association between coronary heart disease risk factors and physical fitness in healthy adult women Circulation, 67 (5): 977-983.

Glagov, S.; Rowley, D.A.; Cramer, D.B.; Page, R.G. (1970) Heart rates during 24 hours of usual activity for 100 normal men. J.Appl. Physiol. 29 (6): 799-805.

Godfrey, S.; Davies, C.T.M.; Wozniak, E.; Bomes C.A. (1971) Cardiorespiratory response to exercise in normal children. Clinical Sci. 40: 419-431.

Godin, G. & Shephard, R.J. (1985) A simple method to assess exercise behaviour in the community. Can.J.Appl.Sports Sciences, 10: 141-146.

Goode, R.C.; Virgin, A.; Romet, T.T.; Crawford, P.; Duffin, J.; Pallindi, T.; Woch, Z. (1976) Effects of a short period of physical activity in adolescent boys and girls. Can. J.Sports Sci. 1: 241 - 250.

Gretebeck, R.J. & Montoye, H.J. (1992) Variability of some objective measures of physical activity. Med.Sci.Sports Exer.24, (10): 1167-1172.

Gretebeck, R.J.; Montoye, H.J.; Ballor, D.; Montoye, A.P. (1991) Comment on heart rate recording in field studies. J.Sports Med. Phys.Fitness. 31: 629-631.

Gutin,B.; Manos, T.; Strong, W. (1992) Defining health and fitness: First step toward establishing children's fitness standards. Res.Q.Ex.Sport. 63 (2): 128 - 132.

Hale, T.; Armstrong, N.; Hardman, A.; Jakeman, P.; Sharp, C.; Winter, E. (1988) Position statement on the physiological assessment on the elite competitor. British Association of Sports Science (BASS), Leeds.

Hansen, H.S.; Froberg, K; Hyldebrandt, N.; Neilsen, J.R. (1991) A controlled study of eight months of physical training and reduction of blood pressure in children: the Odense school children study. BMJ, 303: 682-685.

Haskell, W.L. (1994) Physical/physiological/biological outcomes of physical activity. In, Quinney H.A., Gauvin, L. & Wall, A.E.T.(Eds.) Toward Active Living: 17-23. Human Kinetic Publishers, Champaign, Il.

Haskell, W.L.; Yee, M.C.; Evans, A.; Irby, P.J. (1993) Simultaneous measurements of heart rate and body motion to quantitate physical activity. Med.Sci.Sports Exer. 25, (1), 109-115.

Haskell, W.L.; Montoye, H.J.; Orenstein, D.R. (1985) Physical activity and exercise to achieve health related components of physical fitness. Public Health Reports. 100: 202-212.

Haskell, W.L. (1984) Exercise induced changes in plasma lipids and lipoproteins. Preventative Medicine, 13: 23-36.

Heart Beat Wales Technical Report, No.23 (1987) Exercise for Health. Cardiff

Heart Beat Wales Technical Report No.24(1992) Recent Trends in Lifestyle in Wales, 1985 - 1990. Cardiff

Health of the Nation: A strategy for health in England. (1992) Secretary of State for Health, Government White Paper, HMSO, London.

Health Education Authority (1995) Moving On: International Perspectives on promoting physical activity. HEA, London.

Health Education Board for Scotland. Strategic Plan 1992 - 1997 (1992). Health Education Board for Scotland, Edinburgh.

Hebbelinck, M. & Shephard, R.J. (1981) (Eds) Fitness of a Nation. Medicine and Sport Science. Karger, Basel.

Helmrich, S.P.; Ragland, D.R.; Leung, R.W.; Paffenbarger, R.S.. Jr. (1991) Physical activity and reduced incidence of non insulin dependent diabetes mellitus. New Eng.J.Med. 325: 147-152.

Hendry, L. (1993) Young peoples leisure and lifestyles. Routledge, London.

Hendry, L.B.; Shucksmith J.; Love J.G. (1989) Young people's leisure and lifestyles: Report of Phase 1, 1985 - 1989. The Scottish Sports Council, Edinburgh.

Henriksson, J. (1992) Effects of physical training on the metabolism of skeletal muscle. Diabetes Care, 15 (4): 1701-1711.

Hill, A.V. & Lupton, H. (1923) Muscular exercise, lactic acid and the supply utilisation of oxygen. Q.J.Med. 16: 135-171.

Hillman, M.; Adams J.; Whitelegg J. (1993) One false move. Institute of Policy Studies, London.

Hunsicker, P.A. & Reiff, G. (1977) Youth Fitness Report 1958-1965-1975. J.Phys.Ed.Rec.48(1): 31-33.

Janz, K.F.; Golden, J.C.; Hansen, J.R.; Mahoney, L.T.(1992) Heart rate monitoring of physical activity and adolescents. The Muscatine Study. Pediatrics. 89.256 - 261.

Johnson, M.K. & Foley, M.A.(1984) Differentiating fact from fantasy: the reliability of children's memory. J.Social Issues. 40 (2): 33-50.

Johnston, F.E. & Mack, R.W. (1985) Interobserver reliability of skinfold measurements in infants and young children. Amer.J.Phys.Anthr. 67: 285-290.

Kannel, W.B. & Sorlie, P.D (1979) Some health benefits of physical activity. The Framingham Study. Arch.Intern.Med 139:857.

Karvonen, J.; Chwalbinska-Moneta, J.; Saynajakangas, S. (1984) Comparison of heart rates measured by ECG and microcomputer. Physician & Sports Med. 12 (6): 65-69.

Kasch, F.W.; Phillips, W.H.; Ross, W.D; Carter, J.E.L.; Boyer, J.L. (1966) A comparison of maximal oxygen uptake by treadmill and step test procedures. J.Applied Physiol. 21 (4): 1387-1388.

Katch, V.L. (1983) Physical conditioning of children. J.Adol.Health Care. 3:241-246.

Kemper, H.C.G; & Verchuur, R. (1990) Longitudinal study of coronary risk factors during adolescence and young adulthood - The Amsterdam Growth and Health Study. Ped.Ex.Sci. 2, (4):359 - 371.

Kemper, H.C.G.; Verchuur, R.; de Mey, L. (1989) Longitudinal changes of aerobic fitness in youth ages 12 to 23. Ped.Ex.Sci. 1: 257 - 270.

Kemper, H.C.G.; Verchuur, R.; Storm-van Essen, L.; van Aalst, R. (1986a) Longitudinal study of maximal aerobic power in boys and girls from 12 to 23 years. In Rutenfranz J, Mocellin & Klimt (Eds), Children and Exercise XII, International Series on Sports Science, Vol. 17: 203 - 211. Human Kinetics, Champaign, Il.

Kemper, H.C.G.; Verchuur, R.; Ritmeester, J.W. (1986b) Maximal aerobic power in early and late maturering teenagers. In Rutenfranz J, Mocellin & Klimt (Eds), Children and Exercise XII, International Series on Sports Science, 17: 213 - 225. Human Kinetics, Champaign, Il.

Kerfoot, R.W. (1994) To analyse the feasibility of introducing a doctors (GP's) referral scheme at Newmarket Sports Centre. Anglia Polytechnic University, Cambridge & Forest Heath District Council.

Kitney, R.I. & Rompelman, O. (1980) The study of heart rate variability. Clarendon Press, Oxford.

Klein, P.D; James, W.P.T.; Wong, W.W. et al (1984) Calorimetric validation of the doubly labelled water method for determination of energy expenditure in man. Human Nutr. Clin. Nutr. 38c: 95-106.

Klesges, L.M. & Klesges, R.C. (1987) The assessment of children's physical activity: a comparison of methods. Med.Sci. Sports Med. 19 (5), 511-517.

Klesges, R.C.; Coates, T.J.; Molderhauer, L.M. (1983) The FATS: An observational system for assessing physical activity in children and associated parent behaviour. Behav. Assessment 6: 333-345.

Klissouras, V. (1971) Heritability of adaptive variation. J.Appl.Physiol. 31: 338-344.

Kobayashi, K; Kitamura, K.; Miura, M.; Sodeyama, H.; Murase, Y.; Miyashita, M.; Matsui, H. (1978) Aerobic power as related to body growth and training in Japanese boys: A longitudinal study. J.Appl.Physiol. 44(5): 666-672.

Krahenbuhl, G.S.; Skinner, J.S.; Kohrt, W.M. (1985) Developmental aspects of maximal aerobic power in children. Exer. Sports Sci. Rev. 12: 503 - 538.

Krahenbuhl, G.S.; Pangranzi, R.P.; Petersen, G.W.; Burkett, L.N.; Schneider, N.J. (1978) Field testing cardiorespiratory fitness in primary school children. Med.Sci.Sports Ex., 10:208 -213.

Krahenbuhl, G.S.; Pangranzi, R.P.; Burkett, L.N.; Schneider, N.J.; Petersen, G.W. (1977) Field estimation of VO_2 max in children eight years of age. Med.Sci.Sports Ex., 9:37-40.

Kwee, A. & Wilmore, J.H. (1990) Cardiorespiratory fitness and risk factors for coronary artery disease in 8 to 15 year old boys. Ped.Ex.Sci. 2: 372-333.

Lamb, K.L & Brodie, D.A. (1990) The assessment of physical activity by leisure time physical activity questionnaires. Sports Med., 10 (3): 159-180.

Landers, D.M. & Petruzello, S.J. (1994) The effectiveness of exercise and physical activity in reducing anxiety and reactivity to psychosocial stressors. In, Towards Active Living, Quinney, H.A.; Gauvin, L.& Wall, A.E.T.(Eds): 77-82. Human Kinetic Publishers, Champaign, Il.

Lange Anderson, K.; Ilmarinen, J.; Rutenfranz, J.; Ottmann, W.; Berndt, I.; Kylian, H.; Ruppel, M. (1984) Leisure time sport activities and maximal aerobic power during late adolescence. Euro.J.Appl.Physiol. 52:431-436.

Lange Anderson, K.; Masironi, R.; Rutenfranz, J.; Seliger, V.(Eds) (1978) Habitual physical activity and health. WHO Regional Publications, European Series No.6. WHO, Copenhagen.

Lange Anderson, K.; Seliger, V.; Rutenfranz, R.; Skrobak-Kaczynski, J. (1976) Physical performance capacity of children in Norway: The rate of growth in maximal aerobic power and the influence of improved physical education of children in a rural community. Euro.J.Appl.Physiol. 35: 49-58.

Lange Anderson, K.; Seliger, V.; Rutenfranz, J.; Mocellin, R. (1974) Physical performance capacity of children in Norway. Part 1: Population parameters in a rural inland community with regard to maximal aerobic power. Euro.J.Appl.Physiol. 33: 177 - 195.

Laporte, R.E.; Dearwater, M.D.; Cauley, J.A.; Slemenda, C.; Cook, T.(1985) Physical activity or cardiovascular fitness - Which is more important for health? Physician & Sports Med. 13,(3): 145-150.

Laporte, R.E.; Montoye, H.J. & Caspersen, C.J. (1985) Assessment of physical activity in epidemiological research: Problems and prospects. Public Health Reports 100 (2): 131-146.

Lauer, R.M.; Clarke, W.R.; Beaglehole, R. (1984) Level, trend and variability of blood pressure during childhood: The Muscatine Study. Circulation, 69 (2): 242-249.

Lauer, R.M.; Conner, W.E.; Leaverton, P.E.; Reiter, M.A.; Clarke, W.R. (1975) Coronary heart disease risk factors in school children: The Muscatine study. J.Pediatrics. 86 (5): 697-706.

LeBlanc, J.A. (1957) Use of heart rate as an index of work output. J.Appl.Physiol. 10: 275-280.

Lee, A.; Paffenbarger, R.S.; Hsieh, C. (1992) Time trends in physical activity among college alumni, 1962-1988. Am.J.Epid. 135 (8): 915-925.

Leger, L.A. & Lambert, J. (1982) A maximal multistage 20m shuttle run test to predict VO2max. Eur.J.Appl.Physiol. 49: 1 - 12.

Leger,L.A.; Mercier, D.; Gadoury, C.; Lambert, J. (1988) The multistage 20m shuttle run test for aerobic fitness. J.Sports Sci. 6: 93 - 101.

Leger, L. & Thiverge, M. (1988) Heart rate monitors: Validity, stability and functionality. Physician & Sports Med. 16 (5): 143-151.

Lifson, N.; Gordon, G.B.; McClintock, R. (1955) Measurement of total carbon dioxide production by means of doubly labelled water. J.Appl.Physiol. 7:704-710.

Linsted, K.D.; Tonstad, S.; Kuzma, J.W. (1991) Self report physical activity and patterns of mortality in seventh day adventist men. J. Clinical Epid. 44: 355 - 364.

Livingstone, M.B.E.; Coward, W.A.; Prentice, A.M.; Davies, P.S.W.; Strain, J.J.; McKenna, P.G.; Mahoney, C.A.; White, J.A.; Stewart, C.M.; Kerr, M.J. (1992) Daily energy expenditure in free living children; comparison of heart rate monitoring with the doubly labelled water ($^2H_2{}^{18}O$) method. Amer.J.Clin.Nutr. 56: 343 - 352.

Livingstone, M.B.E. (1994) Energy expenditure and physical acitivity in relation to fitness in children. Proceedings of the Nutrition Society. 53: 207 - 221.

Lochen, M.L. & Rasmussen, K. (1992) The Tromso study: Physical fitness, self reported physical activity and their relationship to other coronary risk factors. J.Epid.Com.Health. 46: 103 - 107.

Lohman T.G.; Roche, A.F.; Martorell, R. (Eds) Anthropometric standardisation reference manual. Abridged Edition. (1991) Human Kinetics, Champaign, Il.

Lord, J. (1993) Exercise on prescription: Evaluation Report. Stockport Health Authorities & Stockport Leisure Services Department.

Macek, M.; Bell, D.; Rutenfranz, J.; Vavra, J.; Masopust, J.; Neidhart, B.; Schmidt, K.H. (1989) A comparison of coronary risk factors in groups of trained and untrained adolescents. Euro.J.Applied Physiol. 58: 577-582.

MacNaughton, L.; Croft, R.; Pennicott, J.; Long, T. (1990) The 5 and 15 minute runs as predictors of aerobic capacity in high school students. J.Sports Med.Phys.Fitness, 30: 24-28.

Mahoney, C. (1992) Twenty metre shuttle run test and PWC170 validity in non-caucasian children in the UK. Brit.J.Sports Med. 26 (1): 45-47.

Malina, R.M. (1986) Energy expenditure and physical activity during childhood and youth. In, Demirjian (Ed) Human growth: A multidisciplinary review. 215-225. London, Taylor and Francis.

Malina, R.M. (1990) Growth, exercise, fitness and later health outcomes. In C.Bouchard et al (Eds) Exercise, fitness and health: A consensus of current knowledge. 637-665. Human Kinetic Publishers, Champaign,Il.

Manson, J.E.; Rimm, E.B.; Stampfer, M.J.; Colditz, G.A.; Willett, W.C.; Krolewski, A.S.; Rosner, B.; Hennekens, C.H.; Speizer, F. (1991) Physical activity and the incidence of non insulin dependent diabetes mellitus. Lancet, 338:774-778.

Marsh, H.W. (1993) The multidimensional structure of physical fitness: Invariance over gender and age. Res.Q.Ex.Sport. 64 (3): 256 - 273.

McCunney, R.J. (1987) Fitness, heart disease and high density of lipoproteins: a look at the relationship. Physician & Sports Med.15 (2):67-69.

McCusker, J. (1988) Young peoples sports participation in Stirling. Scottish Sports Council, Edinburgh.

McHenry, P.L.; Ellestad, M.H.; Fletcher,G.G.; Froelicher, V.; Hartley, H.; Mitchell, J.H.; Sivarajan, E.S. (1990) Statement on Exercise: A position statement for health professionals by the Commitee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association. Circulation. 81 (1): 396 - 398.

Montoye, H.J. (1986) Physical activity, physical fitness and heart disease risk factors in children. In, Stull & Eckert (Eds) Effects of physical activity on children, 127-152. Human Kinetic Publishers, Champaign, Il.

Montoye, H.J. (1985) Risk indicators for cardiovascular disease in relation to physical activity in youth. In, Binkhorst & Kemper (Eds) Children and Exercise XI. Human Kinetic Publishers, Champaign, Il.

Montoye, H.J. & Taylor, H.L. (1984) Measurement of physical activity in population studies: A review. Human Biol. 56: 195-216.

Montoye, H.J.; Washburn, R.; Servais, S. (1983) Estimation of energy expenditure by a portable accelerometer. Med.Sci.Sports Exer. 15: 403-407.

Morris, J.N.; Clayton, D.G.; Everitt, M.G.; Semmence, A.M.; Burgess, E.H. (1990) Exercise in leisure time, coronary attack and death rates. Brit.Heart J. 63: 325 - 334.

Morris, J.N.; Everitt, M.G.; Pollard, R.; Chave, S.P.W.; Semmence, A.M. (1980) Vigorous exercise in leisure time: Protection against coronary heart disease. Lancet, 2: 1207-1210.

Morris, J.N.; Heady, J.A.; Raffle, P.A.B.; Roberts, C.G.; Parks, J.W.(1953) Coronary heart disease and physical activity of work. Lancet. 1053 - 1057, 1111-1120.

Morrow, J.R. & Freedson, P.S. (1994) Relationship between habitual physical activity and aerobic fitness in adolescents. Ped Ex. Sci. 6 (4): 315-329.

Morse, M.; Schultz, F.W.; Cassels, D.E. (1949) Relation of age to physiological responses of the older boy (10 to 17 years) to exercise. J.Appl.Physiol. 1: 683 - 709.

Mueller, J.K; Gossard, D.; Adams, F.R.; Taylor, C.B.; Haskell, W.L.; Kraemer, H.C.; Ahn, D.K.; Burnett, K.; DeBusk, R.F. (1986) Assessment of predicted increases in physical activity: Application of a new method for microprocessor analysis of heart rate. Am.J.Cardiol. 57: 441 -445.

Mutrie, N. (1987) Psychology of Exercise: What makes people continue or drop out? In, Exercise, Heart & Health - A report by the Coronary Prevention Group.

Myers, J.; Walsh, D.; Sullivan, M.; Froelicher, V. (1990) Effect of sampling on variability and plateau in oxygen uptake. J.Appl.Physiol. 68: 404-410.

Nagle, F.J.; Balke, B.& Naughton, J.P.(1965) Gradational step tests for assessing work capacity. J.Appl.Physiol., 20 (4): 745-748.

Newman, W.P.; Freedman, D.S.; Voors, A.W.; Gard, P.D.; Shrinivasan, S.R.; Cresanta, J.L.; Williamson, G.D.; Webber, L.S.; Berenson, G.S. (1986) Relation of serum lipoprotein levels and systolic blood pressure to early atherosclerosis. New Eng.J.Med. 314:138-144.

Neyland, C. (1995). The reliability and validity of measures of resting heart rate. Bsc(Hons) Dissertation, Physiotherapy Dept, Queen Margaret College, Edin, (unpublished).

Nora, J.J.; Lortscher, R.M.; Spangler, R.D.; Nora, A.H.; Kimberlings, W.J.(1980) Genetic epidemiology of early onset ischemic heart disease. Circulation, 61: 503-508.

Nora, J.J. (1980) Identifying the child at risk for coronary heart disease as an adult: A strategy for prevention. J.of Paed. 97: 706-711.

North, T.C.; McCullagh, P.& Tran, Z.V. (1990) Effect of exercise on depression. Exercise and Sport Science Reviews. 18, 379-415.

Northern Ireland Fitness Survey (1989) The fitness, physical activity, attitudes and lifestyles of Northern Ireland post primary school children. Division of Physical and Health Education, Queens University of Belfast. Northern Ireland,1990.

Northern Ireland Health & Fitness Survey (1994) A report by the Division of Physical and Health Education, The Queens University of Belfast.

Office of Population Censuses and Surveys. Occupational mortality 1979-80, 1982-83. (1986) HMSO, London.

O'Hara, N.; Baranowski, I.; Simons Morton, B.G.; Wilson, B.S. (1989) Validity of the observation of children's physical activity. Res.Q.Exer.Sport. 60: 42 - 47.

Osbourne, M. (1992) The Oasis Project, Project Manual. Lagoon Leisure Centre, Hailsham & Wealden District Council, Sussex.

Paffenbarger, R.S.; Hyde, R.T.; Wing, A.L.; Lee, I-Min; Kampert, J.B. (1994) An active and fit way of life influencing health and longevity. In, H.A.Quinney et al, Toward Active Living: 61-68. Human Kinetic Publishers, Champaign, Il.

Paffenbarger, R.S. Jr.; Hyde, R.T.; Wing, A.L. (1990) Chronic disease in former college students: XXXVI. Physical activity and physical fitness as determinants of health and longevity. In, C.Bouchard et al (Eds) Exercise, fitness and health: A consensus of current knowledge: 33-48. Human Kinetics, Champaign, Il.

Paffenbarger, R.S.; Hyde, R.T.; Wing, A.L.; Hsieh, C. (1986) Physical activity, all cause mortality and longevity of college alumni. New Eng.J.Med. 314 (10): 605-613.

Paliczka, V.J.; Nicholls, A.K.; Boreham, C.A.G.(1987) A multistage shuttle run test as a predictor of maximal oxygen uptake in adults. Brit.J.Sports Med. 21,(4): 163 - 165.

Parcel, G.S.; Simons Morton, B.G.; O'Hara, N.M.; Baranowski, T.; Kolbe, L.J.; Bee, D.E. (1987) School promotion of healthful diet and exercise behaviours: An integration of organisational change and social learning theory interventions. J.School Health. 57: 150-156.

Pate, R.R. (1995) Physical activity and health: Dose response issues. Res.Q.Exer. Sport, 66 (4): 313-317.

Pate, R.R.; Pratt, M.; Blair, S.N.; Haskell, W.L.; Macera, C.A; Bouchard, C. et al (1995) Physical activity and public health: A recommendation from the Centres for Disease Control and Prevention and the American College of Sports Medicine. JAMA, 273, 402-407.

Pate, R.R.; Long, B.J.; Heath, G. (1994) Descriptive epidemiology of physical activity in adolescents. Ped.Ex. Sci. 6: 434-447.

Pate, R.R. (1989) The case for large scale physical fitness testing in American youth. Ped. Ex.Sci. 1: 290-294.

Pate,R.R.; Dowda, M.; Ross, J.G. (1990) Associations between physical activity and physical fitness in American children. Amer.J.Dis.Children. 144: 1123 - 1129.

Pate, R.R. & Blair, S.N. (1978) Exercise and the prevention of atherosclerosis: Pediatric Implications. In, Pediatric Aspects of Atherosclerosis. W.Strong (Ed): 251-286. Gruene & Stratton, NY.

Paterson, D.H.; Cunningham, D.A.; Donner, A. (1981) The effect of different treadmill speeds on the variability of VO2 max in children. Euro.J.Appl.Physiol. 47:113-122.

Payne, J.A.; Payne, A.C.; Belton, N.R. (1995a) Blood lipids and energy expenditure in primary school children. Clinical Biochemistry, 28: 358-359.

Payne, J.A.; Payne, A.C.; Belton, N.R.(1995b) The measurement of energy expenditure in young children by the minute by minute heart rate. Proceedings of the Nutrition Society, Paris, France.

Payne, J.A. (1995c) Dept of Child Life & Health, University of Edinburgh, Personal Communication

Payne, J.A.; Payne, A.C.; Belton, N.R. (1994) Energy balance and physical activity in primary school children. Proceedings of the Nutrition Society, Dublin, Ireland.

Payne, V.G. & Morrow, J.R. Jr. (1993) Exercise and VO2 max in children: A meta-analysis. Res.Q.Ex.Sport. 64,(3):305 - 313.

Perrier Study, The: Fitness in America (1979) Perrier - Great Waters of France, Inc. New York.

Perusse, L.; Trembley, A.; Leblanc, C.; Bouchard, C. (1989) Genetic and familial environmental influences on level of habitual physical activity. Am.J.Epid. 129:1012-1022.

Petruzzello, S.J.; Landers, D.M.; Hatfield, B.D.; Kubitz, K.A.; Salazar, W. (1991) A meta-analysis on the anxiety reducing effects of acute and chronic exercise. Sports Med. 11: 143-182.

Physical Education Authority (1987) PE in schools. London: Ling.

Powell, K.E.; Thompson, P.D.; Caspersen, C.J.; Kendrick, J.S. (1987) Physical activity and the incidence of coronary heart disease. Ann.Rev.Pub.Health. 8:253-287.

Presidents Council on Physical Fitness and Sports: National Adult Physical Fitness Survey (1974) Phys.Fitness Res.Digest, 4: 1-27.

Public Health Service. Healthy People 2000. National Health Promotion and Disease Prevention Objectives (DHHS Publication No.PHS 91-50212). Washington DC: US Government Printing Office, 1991.

Pyke, J. (1986) Australian Health and Fitness Survey, 1986. The fitness, health and physical performance of school children. Aust.J.Health Phys.Ed. Rec. 111: 7 - 12.

Ramsbottom, R.; Brewer, J.; Williams, C. (1988) A progressive shuttle run test to estimate maximal oxygen uptake. Brit. J.Sports Med. 22, (4): 141 - 145.

Reiff, G.; Dixon, W.; Jacoby, D.; Ye, G.; Spain, C.; Hunsicker, P.(1986) The Presidents Council on Physical Fitness and Sports National School Population Fitness Survey. Ann Arbor, MI: University of Michigan.

Riddoch, C.J.; Mahoney, C.; Murphy, N.; Cran, G.; Boreham, C. (1992) The predictive power of field tests of physical fitness. J.Sports Sci. 10 (6): 560 - 561.

Riddoch, C. J.; Mahoney, C.; Murphy, N.; Cran, G.; Boreham, C. (1992b) Validation of an activity diary to assess children's moderate and vigorous physical activity. In, Coudert, J. & Van Praagh, E. (Eds) Children & Exercise XVI, Pediatric work physiology: methodological, physiological and pathological aspects: 115-117. Paris, Masson.

Riddoch, C.J.; Savage, J.M.; Murphy, N.; Cran, G.W.; Boreham, C. (1991a) Long term health implications of fitness and physical activity patterns. Arch.Dis.Child. 66:1426-1433.

Riddoch, C.J.; Mahoney, C.; Murphy, N.; Boreham, C.; Cran, G. (1991b) The physical activity patterns of Northern Irish school children, ages 11 - 16 years. Ped.Ex.Sci. 3,(4): 300 - 309.

Riopel, D.A.; Boerth, R.C.; Coates, T.J.; Hennekens, C.H.; Miller, W.W.; Weidman, W.H. (1986) Coronary risk factor modification in children: Exercise. Circulation. 74, (5): 1189A-1191A.

Rivera-Brown, A.M.; Rivera, M.; Frontera, W.R.(1992) Applicability of criteria of VO_2 max in active adolescents. Ped.Ex.Sci. 4,(4): 331 - 339.

Robinson, S. (1938) Experimental studies of physical fitness in relation to age. Arbeitsphysiologie. 10: 251 - 323.

Rohm Young, D. & Steinardt, M.A. (1993) The importance of physical fitness versus physical activity for coronary heart disease risk factors: A cross sectional analysis. Res.Q.Exer. Sport. 64 (4): 377 - 384.

Ross, J.G. & Pate, R.R. (1987) The national children and youth fitness study II: A summary of the findings. J.O.P.E.R.D :51 - 56.

Ross, J.G. & Gilbert, G.G. (1985) The national children and youth fitness study: A summary of the findings. J.O.P.E.R.D. 56 (1): 45 - 50.

Ross, J.G.; Dotson, C.O.; Gilbert, G.G.; Katz, S.J. (1985) The national children and youth fitness study: Maturation & Fitness Test Performance. J.O.P.E.R.D. 67:25-31.

Rowland, T.W. (1993) Aerobic exercise testing protocols. In T.W.Rowland (Ed.) Pediatric Laboratory Exercise Testing: Clinical Guidelines: 19-41. Human Kinetics, Champaign, Il.

Rowland, T.W.; Cunningham, L.N. (1992) Oxygen uptake plateau during maximal treadmill exercise in children. Chest, 101: 485-489.

Rowland, T.W. (1991) Influence of physical activity and fitness on coronary risk factors in children: How strong an argument? Ped. Ex. Sci. 3: 189-191.

Rowland, T.W.; Varzeus, M.R.; Walsh, C.A.(1991) Aerobic responses to walking training in sedentary adolescents. J.Adol.Health Care. 12: 30-34.

Rowland, T.W. (1989) Oxygen uptake and endurance fitness in children: A developmental perspective. Ped.Ex.Sci., 1 (4): 313 - 328.

Rowland, T.W.(1985) Aerobic response to endurance training in prepubertal children. A critical analysis. Med.Sci.Sports Ex. 17: 493-497.

Rowland, T.W. (1981) Physical fitness in children: Implications for the prevention of coronary heart disease. In, Current Problems in Pediatrics. L.Gluck (Ed.), 11 (9):1-54. Chicago, Year Book Med. Publishers.

Royal College of Physicians (1991) Medical Aspects of Exercise: Benefits and Risks. A report by the Royal College of Physicians. London.

Ryhming, I. (1953) A modified Harvard step test for the evaluation of physical fitness. Arbeitsphysiologie, 15: 235-250.

Safrit, M.J. (1990) The validity and reliability of fitness tests for children: A Review. Ped.Ex.Sci., 2: 9-28.

Safrit, M.J.; Glaucia Costa, M.; Hooper, L.M.; Patterson, P.; Ehlert, S.A. (1988) The validity generalization of distance run tests. Can.J.Sport Sci. 13 (4): 188 -196.

Sallis, J.F. & Patrick, K. (1994) Physical activity guidelines for adolescents: Consensus statement. Ped.Ex.Sci. 6 (4): 302-314.

Sallis, J.F. (1993) Epidemiology of physical activity and fitness in children and adolescents. Crit. Rev. Food Sci. Nutr. 33: 403-408.

Sallis, J.F.; Buono, M.J.; Roby, J.J.; Micale, F.G.; Nelson, J.A. (1993) Seven day recall and other physical activity self reports in children and adolescents. Med.Sci.Sports Exer. 25 (1): 99-108.

Sallis, J.F. (1991) Self report measures of children's physical activity. Journal of School Health. 61 (5): 215-219.

Sallis, J.F. & McKenzie, T.L. (1991) Physical education's role in public health. Res.Q.Ex.Sport. 62: 124-137.

Sallis, J.F.; Haskell, W.L.; Wood, P.D.; Fortmann, S.P.; Rogers, T.; Blair, S.N.; Paffenbarger, R.S. Jnr. (1985) Physical activity assessment methodology in the five city project. Amer.J.Epid. 121: 91-106.

Saris, W.H.M.; Elvers, J.W.H.; van't Hof, M.A.; Binkhorst, R.A.(1986) Changes in physical activity of children aged 6 to 12 years. In Rutenfranz J, Mocellin & Klimt (Eds), Children and Exercise XII, International Series on Sports Science, Vol. 17: 121 - 130. Human Kinetic Publishers, Champaign, Il.

Saris, W.H.M. (1986) Habitual physical activity in children: methodology and findings in health and disease. Med.Sci.Sports Exer. 18, (3): 253-263.

Saris, W.H.M. (1985) The assessment and evaluation of daily physical activity in children. A review. Acta Ped. Scand. Suppl. 318:37-48.

Saris, W.H.M. & Binkhorst, R.A. (1977) The use of pedometer and actometer in studying daily physical activity in man. Euro. J.Appl.Physiol. 37: 219-235.

Saunders, C. (1979) Pupils involvement in physical activities in comprehensive schools. Bull. of P.E. 14, (3): 28-37.

Schoeller, D.A. & Webb, P. (1984) Five day comparison of the doubly labelled water method with respiratory gas exchange. Am.J.Clin.Nutr. 40: 153-158.

Schoeller, D.A. (1983) Energy expenditure from doublly labelled water: Some fundamental considerations in humans. Am.J.Clin.Nutr. 38: 999-1005.

Schoeller, D.A. & Van Santen, E. (1982) Measurement of energy expenditure in humans by doubly labelled water method. J.Appl.Physiol. 53: 955-959.
Scottish Consultative Council on the Curriculum. (1989) Curriculum design for the Secondary stages: Guidelines for headteachers, First revised edition. Scottish Consultative Council on the Curriculum, Dundee.

Scottish Sports Council Research Digest No.3 (1993) Sports Participation in Scotland 1992. Scottish Sports Council, Edinburgh.

Scottish Sports Council (1989) School aged team sport: Enquiry group report, 1989. Scottish Sports Council, Edinburgh.

Secondary Heads Association (1991) Enquiry into the provision of physical education in secondary schools. Secondary Heads Association, Aylesbury.

Seefeldt, V. & Vogel, P. (1989) Physical fitness testing of children: A 30 year history of misguided efforts? Ped.Ex.Sci., 1 (4): 295-302.

Seliger, V. & Bartunek, Z. (1971) Physical fitness of the Czechoslovak 12 to 15 year old population. Acta Paed. Scand. Suppl. 217: 37 - 41.

Sengupta, A.; Saka, D.; Muklonadhyay, S.; Gosivamn, P. (1979) Relationship between pulse rate and energy expenditure during graded work at different temperatures. Ergonomics. 22: 1207-1215.

Shaper, A.G. & Wannamethee, G. (1991) Physical activity and ischemic heart disease in middle aged British men. Brit.Heart J. 66: 384 - 394.

Sharkey, B. (1991) New dimensions in Aerobic Fitness: Current Issues in Exercise Science. Human Kinetic Publishers, Champaign, Il.

Sharp, B. (1990) Physical education in Scottish secondary schools: Report of a nationwide survey. Division of Physical Education, Sport and Outdoor Education, Jordanhill College, Glasgow.

Shephard, R.J. & Shek, P.N. (1994) Potential impact of physical activity and sport on the immune system - a brief review. Br.J.Sports Med. 28 (4): 247-255.

Shephard R.J. (1986) Fitness of a nation: Lessons from the Canada fitness survey. In, M.Hebbelinck & R.J. Shephard (Eds), Medicine and Sport Science, Karger, N.Y.

Shephard, R.J.; Jequier, J.C.; Lavallee, H.; LaBarre, R.; Rajic, M.(1980) Habitual physical activity; efects of sex, mileau, season and required activity. J.Sports Med. 20: 55-66.

Shephard, R.J. (1971) The working capacity of school children. In, Frontiers of Fitness, R.J.Shephard (Ed). Charles C.Thomas, Springfield, Il: 319-344.

Shepard, R.J. (1966) The relative merits of step test, bicycle ergometer, and treadmill in the assessment of cardio respiratory fitness. Int. Z.Angew.Physiol. 23: 219-230.

Shvartz, E. & Reibold, R.C. (1990) Aerobic fitness norms for males and females aged 6 to 75 years: A review. Aviat. Space Environ. Med. 61: 3 - 11.

Siconolfi, S.F.; Cullinane, E.M.; Carleton, R.A.; Thompson, P.D. (1982) Assessing oxygen uptake in epidemiological studies: Modification of the Astrand Rhyming Test. Med.Sci.Sports Ex., 14 (5): 335.

Simmons Raithel, K. (1987) Are girls less fit than boys? Physician & Sports Medicine, 15 (11): 157-163.

Simons Morton, B.G.; Parcel, G.S.; O'Hara, N.M.; Blair, S.N.; Pate, R.R. (1988) Health Related Physical Fitness in Childhood. Ann.Rev.Public Health. 9: 403 - 425.

Simons Morton, B.G.; O'Hara, N.M.; Simons Morton, D.G.; Parcel, G.S. (1987) Children and fitness: A public health perspective. Res.Q.Ex.Sport. 58,(4): 295 - 302.

Slaughter, M.H.; Lohman, T.G.; Boileau, R.A.; Horswill, C.A.; Stillman, R.J.; Van Loan, M.D.; Bemben, D.A. (1990) Skinfold equations for estimation of body fatness in children and youth. Human Biol. 60:709 - 723.

Sloan, A.W. (1966) Physical fitness of South African compared with British and American high school children. S.African Med.J. 40: 688 - 690.

Sonstroem, R.J. & Morgan, W.P. (1989) Exercise and self esteem: Rationale and model. Med.Sci.Sports Exercise, 21:329-337.

Sonstroem, R.J. (1984) Exercise and self esteem. In R.J.Terjung (Ed) Exercise and Sport Sciences Reviews, Vol 12: 123-155. Lexington, MA:Collomore.

Sports Council for Wales. (1993) Children's sport participation 1991/92. Sports council for Wales, Cardiff.

Sports Council (1990) Sport in the Community: Into the 90's, a strategy for sport (1988-1993). The Sports Council, London.

Spurr, G.B. & Reina, J.C. (1990) Daily pattern of %VO_2 max and heart rates in normal and undernourished school children. Med.Sci.Sports Ex.22 (5):643-652.

Stanley, J.C. (1971) Reliability. In. R.L. Thorndike (Ed.) Educational measures. Washington DC: American Council on Education.

Stephens, T. (1993) Leisure time physical activity. In, Canada's Health Promotion Survey 1990: Technical Report. T.Stephens & F.D.Graham (Eds) Ottawa, ON: Health & Welfare Canada, 1993, 139-150.

Stephens, T.; Jacobs, D.R.; White, C.C. (1985) A descriptive epidemiology of leisure time physical activity. Public Health Reports. 100: 147 - 158.

Sternfeld, B. (1992) Cancer and the protective effect of physical activity: the epidemiological evidence. Med.Sci.Sports Ex. 24 (11): 1195 - 1209.

Stewart, K.J. & Gutin, B. (1976) Effects of physical training on cardiorespiratory fitness in children. Research Quarterly, 47: 110 - 120.

Storer, T.W.; Davis, J.A.; Caiozzo, V.J. (1990) Accurate prediction of VO_2 max in cycle ergometry. Med.Sci.Sports Ex., 22 (5): 704 - 712.

Strandell, T. (1964) Circulatory studies on healthy old men with special reference to the limitation of the maximal physical working capacity. Acta. Med. Scand, 175 (Suppl.414).

Stratton, G. (1996) Children's heart rates during physical education lessons: A review. Ped.Ex.Sci. 215-233.

Strong, J.P. & McGill, H.C. (1969) The paediatric aspects of atherosclerosis. J. of Atherosclerosis Research, 9: 251 - 265.

Strong, J.P.; Edden, D.A.; Oalmann, M.C. (1972) The natural history geographic pathology & epidemiology of atherosclerosis. In Wisher & Geer (Eds), The Pathogenesis of Atherosclerosis: 20 - 40. Williams & Wilkins, Maryland.

Sunnegarde, J.; Bratteby, L.E.; Sjolin, S. (1985) Physical activity and sports involvement in 8 and 13 year old children in Sweden. Acta Paed.Scand. 74: 904 - 912.

Suter, E. & Hawes, M.R. (1993) Relationship of physical activity, body fat, diet and blood lipid profile in youths 10-15 years. Med.Sci.Sports Ex., 25 (6): 748-754.

Taylor,W. & Baranowski, T. (1991) Physical activity, cardiovascular fitness and adiposity in children. Res.Q.Exer.Sport. 62, (2):157-163.

Taylor, H.L.; Jacobs, D.R.; Schucher, B.; Knudsen, J.; Leon, A.S.; Debacker, G. (1978) A questionnaire for the assessment of leisure time physical activity. J.Chronic Diseases, 31: 741-755.

Telama, R.; Viikara, J.; Valimaki, I.; Siren-Tiusanen, H.; Akerblom, H.K.; Uhari, M.; Dahl, M.; Pesonen, E.; Lahde, P-L; Pietikainen, M.; Suoninen, P. (1985) Atherosclerosis precursors in Finnish children and adolescents.X.Leisure time physical activity. Acta. Paed. Scand. Suppl. 318: 169-180.

Tell, G.S. & Vellar, O.D. (1987) Physical fitness, physical activity and cardiovascular disease risk factors in adolescents: The Oslo Youth Study. Prev.Med., 17: 12-24.

Thirlaway, K. & Benton, D. (1993) Physical activity in primary and secondary school children in West Glamorgan. Health Ed. J. 52 (1): 37-41.

Thomason, H. & Hardman, A.E. (1977) Physical work performance in adolescent girls. Res.Papers Phys.Ed. 3: 27 - 31.

TOYA (Training of Young Athletes) Study: Project Description (1992) The Sports Council, London.

Treiber, F.A.; Musante, L.; Hartdagan, S.; Davis, H.; Levy, M.; Strong, W.B. (1989) Validation of a heart rate monitor with children in laboratory and field settings. Med.Sci.Sports Exer. 21 (3): 338-342.

Tsanakas, J.N.; Bannister, O.M.; Boon, A.W.; Milner, R.D.G. (1986) The "Sport-tester": a device for monitoring the free running test. Arch.Dis.Child. 61: 912-914.

Turley, K.R.; Wilmore, J.H.; Simons Morton, B.; Williston, J.M.; Reeds Epping, J.; Dahlstrom, G. (1994) The reliability and validity of the 9 minute run in third grade children. Ped.Ex.Sci. 6: 178-187.

Tuxworth, W. (1988) The fitness and physical activity of adolescents. Med. J. Aust. Suppl. 148: 13 - 21.

Uemera, K. & Pisa, Z. (1988) Trends in cardiovascular mortality in industrialised countries since 1950. World Health Statistics Quarterly, 41: 115-173.

Uitenbroek,D.G. (1993) Seasonal variation in leisure time physical activity. Med.Sci.Sports. Exer. 25 (6), 755-760.

Uitenbroek, D.G. & McQueen, D.V. (1992) Leisure time physical activity in Scotland: Trends 1987-1991 and the effect of question wording. Soz. Praventivmed.37:113-117.

Vaccaro, P. & Mahon, A.D. (1989) The effects of exercise on coronary heart disease risk factors in children. Sports Med., 8 (3): 139-153.

Van Mechelen, W.; Hlobil, H.; Kemper, H.C.G. (1986) Validation of two running tests as estimates of maximal aerobic power in children. Euro.J.Appl.Physiol. 55: 503-506.

Verchuur, R. & Kemper, H.C.G. (1985) Habitual physical activity in Dutch teenagers measured by heart rate. In, R.A.Binkhorst, H.C.G.Kemper & W.H.M.Saris (Eds) Internation Series on Sport Science, Children and Exercise XI, Vol. 15: 194-202. Human Kinetic Publishers, Champaign, Il.

Vokac, Z.; Bell, H.; Bautz Holter, H.; Rodahl, K. (1975) Oxygen uptake in leg and arm exercise, sitting and standing. J.Appl.Physiol. 39: 54-59.

Wahlund, H. (1948) Determination of physical work capacity. Acta.Med.Scand. (Suppl) 215: 9-86.

Walker, J. & Kindlen, S. (1988) The effect of practice on the measurements of skinfold thickness by an inexperienced observer. Proc.Nutr.Soc. 47: 142A.

Wanamethee, G. & Shaper, A.G. (1992) Physical activity in stroke in middle aged men. BMJ. 204: 597-601.

Washburn, R.A. & Montoye, H.J. (1984) Validity of heart rate as a measure of mean daily energy expenditure (Abstract). Med. Sci.Sports Ex. 16: 196-197.

Watkins, J.; Farrally, M.R.; Powley, A. (1983) The anthropometry and physical fitness of secondary schoolgirls in Strathclyde. The Scottish School of PE. Jordanhill college of Education.

Webber, L.S.; Cresanta, J.L.; Voors, A.W.; Berenson, G.S. (1983) Tracking of cardiovascular disease risk factor variables in school age children. J.Chronic Diseases, 36: 647-660.

Weber,G.; Kartodihardjo, W.; Klissouras, V. (1976) Growth and physical training with reference to heredity. J.Appl.Physiol. 40:211-215.

Welsman, J.R. & Armstrong, N. (1992) Daily physical activity and blood lactate indices of aerobic fitness in children. Br.J.Sp.Med. 26 (4): 228 - 232.

Westerterp, K.R.; deBoer, J.O.; Saris, W.H.M.; Schoffelen, P.F.M.; ten Hoor, F. (1984) Measurement of energy expenditure using doubly labelled water. Int. J.Sports Med. (Suppl.), 5: 74-75.

Weymans, M.L.; Reybrouck, T.M.; Stijns, H.J.; Knops, J. (1986) Influence of habitual levels of physical activity on the cardiorespiratory endurance capacity of children. In Rutenfranz J, Mocellin & Klimt (Eds), Children and Exercise XII, International Series on Sports Science, Vol. 17: 149 - 156. Human Kinetics, Champaign, Il.

Whitehead, J.R.; Pemberton, C.L.; Corbin, C. (1990) Perspectives on the physical fitness testing of children: The case for a realistic educational approach. Ped.Ex.Sci. 2: 111-123.

Wickham, C.A.C.; Walsh, K.; Cooper, C.; Parker, D.J.P.; Margetts, B.M.; Morris, J.; Bruce, S.A. (1989) Dietary calcium, physical activity and risk of hip fracture: A prospective study. BMJ, 299: 889 - 892.

Wilmore, J.H. & Costill, D.L. (1994) Physiology of sport and exercise. Human Kinetic Publishers, Champaign, Il.

Wilmore, J.H. & McNamara, J.J. (1974) Prevalence of coronary heart disease risk factors in boys, 8 to 12 years of age. J.Pediatrics. 84 (4): 527-533.

World Health Organisation (1986) Ottawa charter on health promotion. Canada Public Health Association, Ottawa.

World Health Organisation (1968) Meeting of investigators on exercise tests in relation to cardiovascular function. (WHO Technical Report 388). WHO, Geneva.

Yoshizawa, S.; Ishizaki, T.; Honda, H. (1986) Aerobic power and endurance running in young children. In Rutenfranz J, Mocellin & Klimt (Eds), Children and Exercise XII, International Series on Sports Science, Vol. 17: 77 - 90. Human Kinetic Publishers, Champaign, Il.